ON MULTI-IMAGE RECONSTRUCTION FROM HISTORIC PHOTOGRAPHS

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ABSTRACT

The ultimate purpose of this work is to reconstruct photogrammetrically a distinguished building in the centre of Athens, which has been torn down years ago. Five old photographs were available taken apparently with the same camera, the nominal calibration parameters of which could be somehow 'guessed'. As a first step, it was decided to employ our own bundle-adjustment software, which works within a commercial CAD environment. Besides, unlike most commercially available 3D reconstruction software, it allows full control over the whole adjustment process (by presenting individual image point residuals, producing RMS errors for check points, accommodating additional calibration parameters etc.). A second task was to compare these results with PhotoModeler, in order to evaluate this widely used (but in certain aspects 'obscure') tool against a rigorous photogrammetric approach. Besides solutions with no control information, a few full and partial control points were established from existing architectural drawings, allowing self-calibration procedures. The two software tools produced essentially equivalent results, thus validating the precision of the PhotoModeler approach. However, certain additional features of a proper bundle adjustment program (e.g. recovery of radial lens distortion, self-calibration with minimal or unconventional control), discussed here, may allow a fuller exploitation of the powerful reconstruction and visualisation tools of the PhotoModeler type. It was confirmed that, using suitable software, rigorous approaches can be applied to historic images, and results of reasonable precision may be expected, limited only by possible inaccuracies in scale.

1. INTRODUCTION

Working with historic images (and regrettably this is not all that rare) represents one of the most challenging aspects of architectural photogrammetry. The facts that these mostly depict objects which no longer exist and, hence, cannot be surveyed or photographed anew; that very often no control information is at hand; that the cameras may be unknown; that these photographs have mostly been taken at random – these facts point to the difficulty facing the photogrammetrist. Single-image techniques, to which CIPA Task Group 2 is dedicated, is a topic most studied as regards typically structured man-made objects (Bräuer-Burchardt & Voss, 2001; Petsa et al., 2001; van den Heuvel, 2001). To a certain extent, one might say, the methods could be somewhat standardised in such cases. If overlapping images are available, more options are open, depending on the existing additional information. Double-image or multi-image solutions may be considered, either employing rigorous photogrammetric approaches or using the commercially available (essentially user-oriented) 3D reconstruction tools.

At the present example, both options were taken using the well-established PhotoModeler (3.1) tool and our own bundle adjustment software. Commercial programs, like 3DBuilder or PhotoModeler, have two main aspects. On the one hand, they provide tools allowing fast production of results. Besides, although it is highly questionable whether non-expert users can in fact handle even mildly complicated cases, such programs have greatly contributed to the acceptance of photogrammetry in architectural or archaeological documentation. On the other hand, however, as they do not address the photogrammetrist, they are in no need to offer a full documentation of the algorithms. As a consequence, certain aspects remain obscure, and at some points one may not be sure as to how results have been obtained, which is the actual accuracy, whether any assumptions have been made etc. In the framework of the 3D reconstruction of a demolished building in Athens, several of the above issues have also been investigated.

Built in 1870 by an unknown architect, the 'Tsopotos' residence was, until its demolition, a characteristic Athenian house, partly imitating a particular ancient Greek monument (Fig. 1).

Figure 1. The 'Tsopotos' residence painted by the distinguished poet and painter N. Egonopoulos (Egonopoulos, 2001).

2. IMAGES AND SOFTWARE

2.1 The historic photographs

Five medium format historic photographs of this building were available (Fig. 2). Although it is was obvious that they had been acquired at different times, the photographer was known to the source (ΕΛΙΑ Archives), and it was assumed that in all probability the same camera, with a normal 80 mm lens, had been used. This was confirmed by using two vanishing points on images, which (ignoring the principal point) are sufficient for an estimation of the camera constant.

2.2 The bundle adjustment program

Besides PhotoModeler, as mentioned already, our own bundle adjustment software was used. This particular program, named

BASTA and documented in Kalisperakis & Tzakos (2001), has been primarily intended as an educational tool. It functions totally within a commercial CAD environment, exploiting its tools to allow convenient image measurement as well as editing.

Figure 2. The five images of the 'Tsopotos' residence.

The program solves the bundle without control ('relative solution'); it offers options for both full and partial self-calibration (camera constant, principal point and/or radial lens distortion); it may handle control coordinates as observations; further, it can accept any of the three geodetic coordinates of control points as known and the others as unknowns, a very useful feature in the context of architectural photogrammetry (see 4.2). For both programs the same 92 tie points were used, but image coordinates were measured independently within the two environments. An average of 3.7 intersecting rays per object point formed a strong bundle configuration. The image at the bottom of Fig. 2 has a larger scale. Adjustments for all 5 images but also for the remaining 4 have been carried out to check for any possible differences due to this particular image (Rova, 2003).

3. ADJUSTMENTS WITHOUT CONTROL

As no particularly reliable control coordinates were at hand (see 4.1 below), the first step was to solve the bundle without geodetic control, i.e. in arbitrary systems, properly scaled in the case of BASTA whose results were considered as reference data regarding PhotoModeler. Outcome of the adjustments, which relied on the assumed 'nominal' values for inner orientation parameters c = 80 mm and $x_o = y_o = 0$, is 92 tie point coordinates in the two systems of BASTA and of PhotoModeler (*B* and *PM*, respectively). Point sets represent shape reconstruction and can be compared to each other by means of a 3D similarity transformation (Rova, 2003). The overall standard error (σ_S) of this transformation in all three axes describes the 'closeness' of results from the two programs.

Other measures of precision are also available. For BASTA, this is the standard error of image coordinates (σ_o) and, further, the overall standard deviation (σ_T) of tie points, resulting from the variance-covariance matrix of unknowns in the bundle adjustment. On the other hand, PhotoModeler produces a 'tightness' value (t) for every tie point, representing the maximum distance among intersecting rays as percentage of the largest object dimension. Furthermore, PhotoModeler can perform what it calls a 'self-calibration' (from now on *PMS*), meaning a small 'internal' adjustment of camera parameters to 'optimize' the solution; however, users do not actually see it. Results from the two programs are concentrated in Table 1. In Table 2 results from the 3D similarity transformations are given.

Table 1. Precision estimations from 92 tie points

		B	*PM*	*PMS*
4 images	σ_o (μm)	18.3		
	σ_T (cm)	1.3		
	t (cm)		3.8	4.0
5 images	σ_o (μm)	19.2		
	σ_T (cm)	1.5		
	t (cm)		3.3	3.2

Table 2. Accuracy σ_S (cm) of the 3D similarity transformations

	B – PM	*B – PMS*
4 images	2.0	1.9
5 images	2.0	1.9

Image residuals (represented as $\sigma_o \approx 1.3$ pixel) and tie point precision σ_T are acceptable if the poor quality of object points, due to building decay, is taken into account. 'Tightness' values from PhotoModeler (being larger than σ_T by a factor 2 to 3) appear to be grossly comparable to σ_T since they refer to the largest deviations among rays. Finally, the similarity measures σ_S in Table 2 between point sets confirm that reconstructed shapes are practically equivalent, within the precision of the two methods.

4. SELF-CALIBRATING ADJUSTMENTS

Besides defining the object system, the use of control points can also allow a self-calibrating approach to optimize reconstruction (and, additionally, provide information about camera geometry). In the present case, separate old elevation drawings prepared by students at the School of Architecture of NTUA were available. A few control points, unfavourably distributed but sufficient for self-calibration, were extracted graphically. Being of unknown accuracy, however, the plots were regarded as unreliable (a fact also established in the experiments). Under these circumstances, the next tests were essentially intended to check the camera calibration processes rather than the accuracy of space coordinates.

4.1 Use of control points

PhotoModeler does not allow recovery of lens distortion (but it accepts existing data about it). After some experimenting, it was concluded that, for 5 images, camera constant (c) and principal point (x_o, y_o) could be determined from 7 control points (at least 5 / image). For 4 images, 6 points were required on all images (5 points / image did not suffice for the principal point); tests were made with 7 control points, too. The same control was also used for self-calibration in BASTA (both with and without estimation of radial lens distortion). Being theoretically in the same object system, the point sets from the two programs were directly compared, to produce a mean RMS deviation (d). Additionally, they were compared with a rigid body transformation (giving a mean standard error σ_R), to check for small translations and rotations between the two 3D point sets. Table 3 presents the outcome of these comparisons according to number of images and ground control points (GCP).

Table 3. RMS differences (d) and error (σ_R) of rigid body transformation between point sets after self-calibration

		B – PM		*B – PMS*	
images	GCP	d (cm)	σ_R (cm)	d (cm)	σ_R (cm)
4	6	3.9	2.8	3.0	2.3
4	7	2.8	2.1	3.1	2.0
5	7	2.8	2.0	2.7	2.0

It is seen in σ_R that, with the exception of 6 control points, the point sets indeed remain within the precision of reconstruction, as presented in Table 2. However, certain significant differences do exist between the two points sets, seen in the values of d, due to translation and rotation between the object systems. In fact, large differences are present even when comparing results from the same program obtained using different control points, a consequence of control point uncertainty. What is to be noted here, however, is that the two programs are affected differently by the inaccuracy of the same control points.

A probably more interesting aspect of self-calibration is the results as regards camera geometry, seen in Tables 4 and 5 (in the second case solutions are given with and without distortion).

Table 4. Calibration results from PhotoModeler

		PM			*PMS*		
images	GCP	c (mm)	x_o (mm)	y_o (mm)	c (mm)	x_o (mm)	y_o (mm)
4	6	81.617	0.010	–0.004	81.582	0.012	–0.003
4	7	79.211	0.006	–0.001	79.273	0.003	–0.000
5	7	79.374	0.004	–0.000	79.172	0.008	–0.001

Table 5. Calibration results from bundle adjustment (BASTA)

images	GCP	c (mm)	x_o (mm)	y_o (mm)	k_1	k_2
4	6	79.011 78.927	–0.171 0.257	0.118 0.187	 6.8×10^{-7}	 2.1×10^{-9}
4	7	79.011 78.934	–0.219 0.186	0.140 0.204	 5.9×10^{-7}	 2.0×10^{-9}
5	7	79.170 79.083	–0.046 0.061	0.308 0.082	 2.4×10^{-6}	 -5.6×10^{-10}

PhotoModeler yields a principal point ‘suspiciously’ coincident with the image centre (it is not known to these authors whether the program imposes some internal constraint to principal point location). The bundle adjustments result in a scatter of the x_o, y_o values, generally expected when adjusting non-metric images. On the other hand, BASTA shows a very strong repeatability regarding the camera constant; the results from PhotoModeler, on the contrary, are more scattered, reaching a very large difference when using 6 control points. The radial distortion estimated by BASTA differs somewhat in the cases of 4 and 5 images; nevertheless, its value is quite small for this normal lens (the calibrated curve does not exceed 40 μm at image corners). But if wide-angle lenses are used, the problem of distortion in PhotoModeler must be tackled by partial camera pre-calibration (for simple approaches see Karras & Mavromati, 2001).

4.2 Use of ‘indirect’ control information

Reference has already been made to the fact that BASTA accepts control points with only one or two known object space coordinates (the remaining ones are estimated as ‘partial’ tie points in the adjustments). This particular feature has proved very useful indeed in architectural applications, where control might not be available but the regular geometry of the object can be exploited instead. Considering the example of Fig. 3, one sees that a given horizontal length *L* on a planar façade XY allows generating 2 full control points (1,2) and points with known X,Z (like point 6), known Y,Z (points 3,4) or points simply on the plane (point 5). Evidently, additional points on perpendicular planes (known X or Y or both) may also be considered.

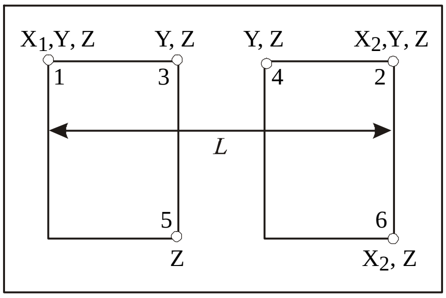

Figure 3. Example for defining ‘partial’ control points by using one known dimension *L* and exploiting object geometry.

This approach has been applied in the present case to allow self-calibration, the results of which are seen in Table 6. The known horizontal length was taken on the left XY façade, giving rise to 2 full (X,Y,Z) control points. One more point was chosen on the horizontal line (known Y,Z); and three further points on the façade were also used (known Z).

Table 6. Calibration results from BASTA with ‘indirect’ control (GCP: 2 full; 1 with known Y, Z; 3 with known Z)

images	c (mm)	x_o (mm)	y_o (mm)	k_1	k_2
4	79.012 78.927	–0.185 0.247	0.124 0.193	 6.9×10^{-7}	 2.1×10^{-9}
5	79.170 79.078	–0.023 0.088	0.303 0.069	 2.5×10^{-6}	 -6.0×10^{-10}

Comparison of Tables 6 and Table 5 reveals that self-calibration essentially relying on a single known dimension in object space and making use of certain object properties yields identical camera calibration results to those from full control points. Since the plots at hand appear, from a purely metric point of view, as rather questionable, this is probably the approach to be adopted for the next steps of the present project.

5. DISCUSSION

Suitable tools exist today for conveniently handling tasks of architectural photogrammetry, including instances were historic, usually poorly documented photographs need to be used. PhotoModeler is such a powerful 3D reconstruction tool. Although certain of its processes may remain somewhat ‘obscure’, it has been established here that the reconstruction it provides is equivalent to rigorous photogrammetric solutions. However, certain questions must be answered ‘externally’, such as lens distortion (a considerable problem in several tasks) or the requirement for more flexible means for tackling unconventional data. It seems that the combination of commercial program packages with own software, like the one used here, may prove even more fruitful.

Recently, a ‘new’ set of old images (among them some giving a bird’s eye view) of the building in question have come to the authors’ attention. Students of Architecture again had acquired them. Unless these former students are somehow traced, these enlarged photographs will also require calibration when they will be carried into the adjustment. For now, only a snapshot of a rough textured model can be seen in Fig. 4.

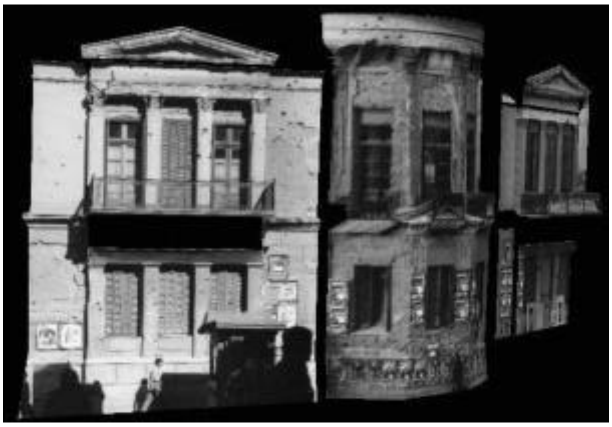

Figure 4. View of the rough model.

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