COMPARISON OF SIMPLE OFF-THE-SELF AND OF WIDE-USE 3D MODELING SOFTWARE TO STRICT PHOTOGRAMMETRIC PROCEDURES FOR CLOSE-RANGE APPLICATIONS

PATIAS P., STYLIANIDIS E., TERZITANOS C.
Department of Cadastre, Photogrammetry and Cartography, The Aristotle University of Thessaloniki, Greece
E-mail: patias@topo.auth.gr

Commission V, Working Group V/5

KEY WORDS : 3D modeling software, simple photogrammetric procedures, close-range applications

ABSTRACT :

3-D surface reconstruction is moving from traditional stereoscopy to reconstruction of surface geometry by many other means including computer graphics modeling, surface texturing and vanishing lines projection. Based on such concepts many pieces of software have emerged, which have been mainly developed by other disciplines (electrical and mechanical engineering, architecture, etc.), they are of wide use and may have the potential of simple photogrammetric systems, especially in the case when the user is not photogrammetrist and the accuracy requirements are not very strict. In any case, however, both their potentiality and the expected quality of the final product should be tested in order to avoid misuse. This work deals with a thorough comparison of such software to strict photogrammetric close range multi-photo procedures for 3-D object reconstruction, texturing and visualization.

1. INTRODUCTION

The main strength of Photogrammetry, that is the reconstruction of an object surface geometry by remotely sensing it, has been recognized also by other disciplines than photogrammetrists. This important merit is currently being enhanced by :

- *a trend to move from traditional stereoscopy to multi-photo surface reconstruction,*
- *the low-cost digital image acquisition capabilities of the current technology* (eg. Boccardo, et.al., 1997),
- *the wide spread of 3D modeling, animation and web-authoring tools* (eg. Hanke, et.al., 1997b)

As a result of this market-pull, many pieces of software have emerged (mainly developed by other disciplines) and they have rather wide acceptance among non-photogrammetrists. These packages may have the potential of simple photogrammetric systems, especially in cases when the accuracy requirements are not very strict.

Since these pieces of software target to non-photogrammetrists they rather put emphasis on the "added-value" of the produced 3D models, than in algorithmic aspects. The accuracy is generally assessed only visually or qualitatively, and very rarely in strict statistical terms. This makes sense for the untrained user, but it is not adequate for the photogrammetrist. More "sophisticated" aspects, such as camera self-calibration, or inclusion of lens distortion models, are generally not addressed. This is expected to generally lead to accuracy deterioration, but its practical significance remains to be checked.

In order to avoid misuse of such software, it is important that both their potentiality and the expected quality of the final product should be tested, against strict photogrammetric procedures.

This work deals with a comparison of 3D BUILDER, a typical example of such software family, to strict photogrammetric close-range multi-photo procedures (Rollei CDW-2000) for 3D object reconstruction.

2. 3D BUILDER CHARACTERISTICS

3D-BUILDER by 3D Construction Company is a low-cost "photogrammetric" tool, which uses a comfortable Windows user interface. It claims that "by using a powerful and comprehensive math solver" is able to combine information from a large number of photos of simple or complicated objects, extract information, and merge it all together into a single 3D model ready to export to a target rendering, animation, CAD or Internet package. It also claims that "it builds dimensionally accurate 3D models".

It imports images (a total of 36 different file formats) taken by analog, digital and video cameras, or digitized by scanners or Photo CD. It finally exports several file formats, including 3D-DXF, 3D-Studio, IGES, Inventor, STL (Stereo Lithography), Wavefront, or VRML files with complete texturing capabilities serving thus as a web-authoring tool, as well.

Camera format and lens focal length is either defined or chosen from an available list. A useful feature is that it can mix lenses in the same project, that is normal, wide-angle as well as close-up lenses can be used at the same time. However, currently, it has no capability of introducing lens distortion parameters.

3D-BUILDER works with one or unlimited number of photos, but requires that the pictures should be taken from an angle. Although the used method is not documented at all, this fact suggests that the perspective is reconstructed through vanishing lines (see eg. Patias and Karras, 1995). In order to define a reference frame the algorithm can use:

- *Measured (X, Y, Z) coordinates of control points.*
- *Measured distances between control points.*
- *Measured coordinates of the camera stations.*
- *Definition of coordinate axis direction lines (hint lines).*
- *Combinations of the above (e.g. known camera height and two coordinate axis pairs).*

The accuracy assessment is provided by 3D BUILDER by projecting the adjusted ground locations of the measured points back on the images, giving also their mean difference in percentage units. Thus the achieved accuracy is only judged graphically and qualitatively.

Other features include project management, viewing, drawing, editing, texturing and material mapping tools, digital filtering, and reverse engineering.

In conclusion, 3D-BUILDER claims to be an easy-to-use, low-cost photogrammetric package, based on relaxed geometric restrictions (can work without known points, distances, or camera positions) and able to produce accurate 3D photogrammetric products.

2. DIGITAL CAMERA CALIBRATION

In order to evaluate the internal accuracy achievable by 3D BUILDER, a preliminary camera calibration procedure was followed. The camera used is the Kodak DCS 420 digital camera (Fig.1).

KODAK DCS 420 Digital Camera		
Camera	:	NIKON N90
Sensor	:	1.5 million pixels (1524 x1012) 13.8 mm x 9.2 mm pixel size 9 μm 36-bit color
Lens	:	Nikon 28mm, F-mount

Figure 1: Kodak DCS420 camera

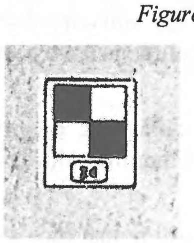

Figure 2: Typical target

The calibration field consists of four vertical planes, on which 11 targeted control points have being surveyed with an accuracy (rms) of 0.1 mm.

The targets have a dimension of 5cm x 5cm (Fig. 2). The calibration field has been imaged from four positions (Fig. 3), producing thus a quadruple of almost 100% overlapping digital images (Fig. 4) at an average scale of 1 : 100.

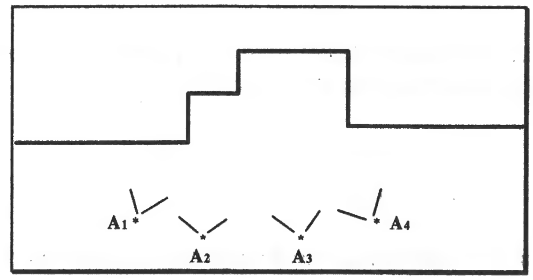

Figure 3: Plan of calibration field and camera positions

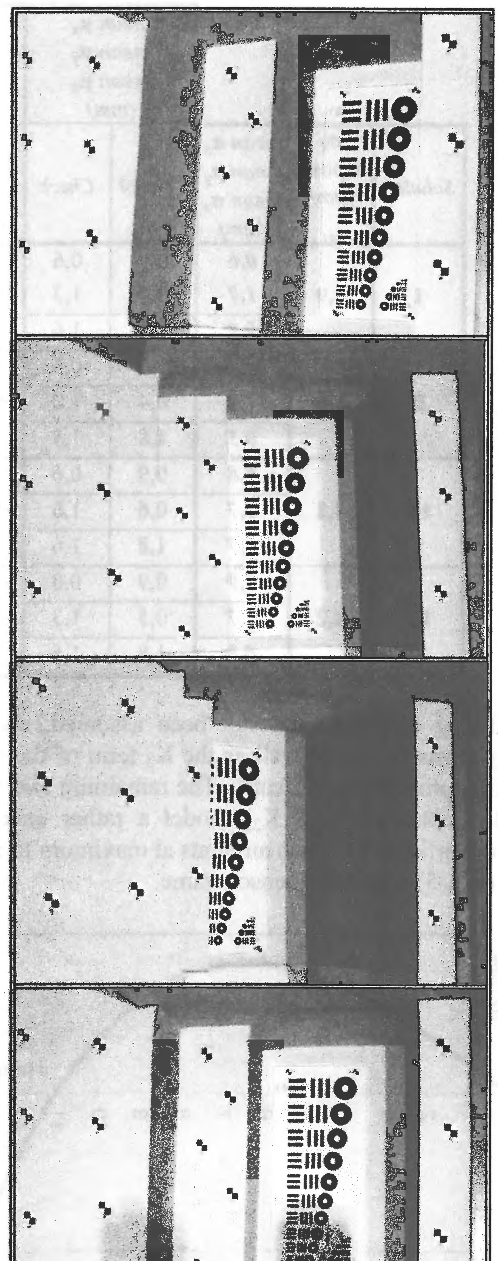

Figure 4: Calibration field digital images

The image coordinates of the 11 targeted points were measured with the Rollei CDW-2000 software, together with 15 natural, but well defined, tie points. The 6 of the 11 targeted points were withheld from the adjustment, in order to serve as check points.

The self-calibration model used (1) includes only radial lens distortion plus two affinity terms :

$$dx = \bar{x}.r.(r^2 - r_0^2).K_1 + \bar{x}.r.(r^4 - r_0^4).K_2 - \bar{x}C_1 + \bar{y}C_2$$
$$dy = \bar{y}.r.(r^2 - r_0^2).K_1 + \bar{y}.r.(r^4 - r_0^4).K_2 - \bar{x}C_2 \quad (1)$$

Several self-calibrating bundle adjustment solutions have been obtained with the use of the Rollei CDW-2000 software (see Table 1).

Table 1: Self-calibration solutions

	No. of points			***Adjusted parameters***						
Solution	Control	Check	Tie	x_o	y_o	c	K_1	K_2	C_1	C_2
I	5	6	15	✓	✓	✓				
II	5	6	15	✓	✓	✓	✓	✓		
III	5	6	15	✓	✓	✓			✓	✓
IV	5	6	15	✓	✓	✓	✓	✓	✓	✓

Table 2: Self-calibration bundle adjustment results

Solution	σo a-post. (*μm*)	*mean* σ_x *mean* σ_y *mean* σ_z (*mm*)	*mean* μ_x *mean* μ_y *mean* μ_z (*mm*) *Control*	*Check*	***Estimated calibration parameters*** x_o (*mm*)	y_o (*mm*)	c (*mm*)	K_1 x 10^{-5}	K_2 x 10^{-8}	C_1 x 10^{-4}	C_2 x 10^{-4}
		0,6	0,9	0,6							
I	**3,9**	***1,7***	1,0	1,3	*-0,218*	*0,153*	*28,764*				
		0,6	2,2	1,6							
		0,5	0,9	0,6							
II	**3,6**	***1,4***	0,4	1,0	*-0,130*	*0,132*	*28,737*	*-3,873*	*-7,086*		
		0,5	1,8	1,3							
		0,8	0,9	0,6							
III	**4,2**	***1,7***	0,6	1,0	*-0,191*	*0,121*	*28,832*			*-2,077*	*3.22*
		0,7	1,8	1,6							
		0,9	0,9	0,8							
IV	**4,2**	***1,7***	0,5	1,3	*-0,052*	*-0,087*	*28,832*	*7,076*	*-1,623*	*-1,279*	*11.47*
		0,8	1,8	1,6							

Decentering distortion has not been assumed, and the affinity terms C_1, C_2 as well as the K_3 term of the radial distortion proved insignificant. The remaining two terms of radial distortion (K_1, K_2) model a rather excessive radial distortion (dr) which amounts at maximum to about 25μm (Fig. 5) within the sensor frame.

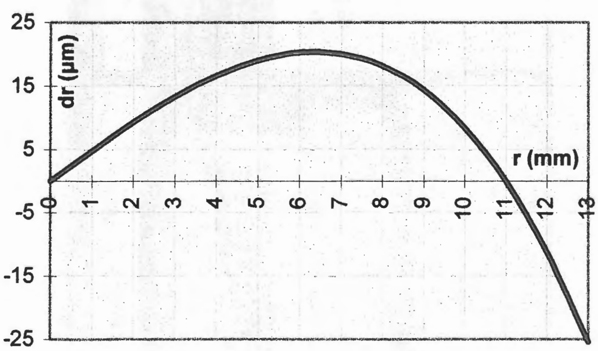

Figure 5: Radial distortion curve for Kodak DCS420

From Table 2, above, it is clear that the best solution is II, giving an a-posteriori rms value of 3.6μm (40% of pixel size), an expected precision of σ_{XZ} = 0.5 mm (planimetry) σ_Y = 1.4 mm (height) and an achieved accuracy (realized at the check points) of μ_{XZ} = 0.9 mm (planimetry) μ_Y =1.0 mm (height).

3. ACCURACY ASSESSMENT OF 3D BUILDER

The same four images have been processed with the 3D BUILDER software, keeping as known the calibrated focal length (*c = 28.737 mm*) and the coordinates of the principal point (*x_0 = - 0.130 mm, y_0 = 0.132 mm*). Radial distortion has not been applied since the software does not provide this option. Two different solutions have been obtained as follows :

- *Solution No.1* uses the bare minimum of 2 control points (no. 24, 34) plus definition of hint lines through the calibration field wall edges.
- *Solution No.2* uses the same 5 control points (no. 21, 24, 25, 27. 34) as the Rollei CDW-2000 solutions.

The achieved accuracy of the above two solutions was evaluated against the strict photogrammetric solution II, provided by the Rollei software. The latter was assumed as "ground truth", and the estimated ground coordinates of the check (now named "Signalized Check points") and the tie points (now named "Natural Check points") as error free. Against this solution, the achieved accuracy of 3D BUILDER is given in Table 3.

Table 3: Accuracy achieved by 3D BUILDER

	No. of check points		***Signalized*** *Check pts.*	***Natural*** *Check pts*	
Solution	Signal.	Natural	*mean* μ_x *mean* μ_y *mean* μ_z *(mm)*	*mean* μ_x *mean* μ_y *mean* μ_z *(mm)*	***3DBuilder*** *accuracy estimate*
1	9	15	*10.2* *16.8* *2.5*	*10.2* *11.4* *8.4*	***0.26 %***
2	6	15	*4.6* *4.0* *1.8*	*5.1* *5.7* *2.2*	***0.13 %***

It should be noted that the accuracy estimate provided by 3D BUILDER refers to image scale and is very optimistic (i.e. 0.13% through the sensor frame of 14mm, multiplied by the image scale of 1:100 refers to 1.8 mm on the ground, which is twice as much the achieved accuracy).

Regarding Solution No.**2**, the achieved accuracy of μ_{XZ} = 2.9 mm (in planimetry, noting that $\mu_{XZ} = (\mu_X \mu_Z)^{1/2}$) and μ_Y = 4.0 mm (height) is 3.2 times worse in planimetry and 4 times worse in height than the strict photogrammetric solution. Moving from signalized to natural points, the accuracy is deteriorated, as expected, with the presence of larger pointing errors.

In Solution No.**1**, the achieved accuracy of μ_{XZ} = 5.0 mm (planimetry) and μ_Y = 16.8 mm (height) is 5.5 times worse in planimetry and 16.8 times worse in height than the strict photogrammetric solution. Very similar results have been obtained also by (Hanke et. al., 1997a).

It should be stressed that part of the accuracy deterioration could be attributed to the current inability of 3D BUILDER to correct for lens distortion. This is quite a disadvantage since the use of amateur cameras and uncalibrated desktop scanners is quite common among its targeted user group. With very simplistic calculations (the realized radial distortion of 25μm enlarged by the average photo scale of 1: 100 gives an uncorrected error of about 2.5 mm), we can assume that if radial lens distortion correction is applied, an increase of two times in accuracy could be expected. Hopefully in the future this software will give the ability to correct for at least radial lens distortion.

4. A PRACTICAL EXAMPLE

In order to both realize the accuracy and the functionality of 3D BUILDER in practical projects, we have used it in recording an archaeological monument; a wall with anaglyph archaic sculptures 4.5 m long by 1.5 m high.

Again the DCS420 camera was used and the wall was imaged in three images at a mean scale of 1: 300 (Fig. 6)

Figure 6: The three images used for the recording

For the processing only 1 control point, 1 distance and 2 pairs of hint lines for axes direction were used. The accuracy of the output 3D model was checked against 6 measured distances on the ground and the their average and maximum difference was 4.2 mm and 15 mm respectively. At the same time the accuracy estimate provided by 3D BUILDER was 0.11 %, meaning 4.6 mm on the ground across the frame.

The images were taken tilted, in order to assure a good vanishing point recovery and a typical 3D BUILDER multi-photo processing screen is shown in Fig.7.

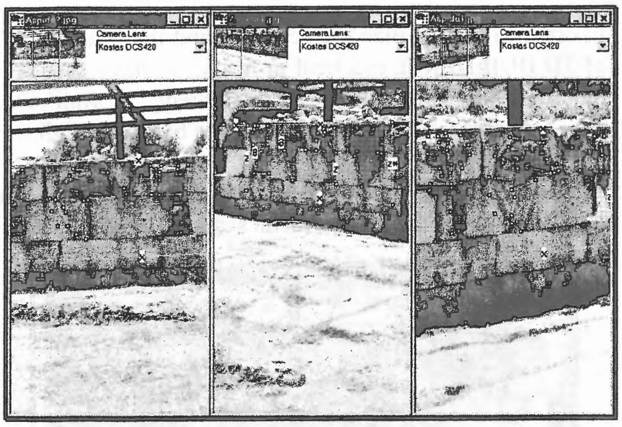

Figure 7: Typical 3D BUILDER multi-photo processing screen

This kind of accuracy fits very well the needs for mapping at 1 : 25 scale, a regular requirement by architects and archaeologists.

Further, the three images were processed and a 3D wire frame as well a draped photo model were produced (Figs 8 and 9).

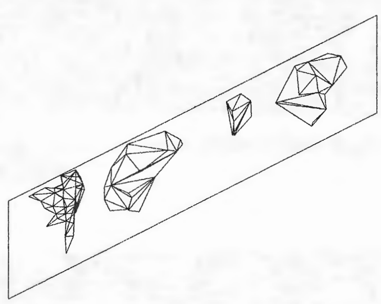

Figure 8: The produced 3D wire-frame model

Figure 9: The produced 3D photo-textured model

These 3D models can be either inserted in a CAD environment for further processing and modeling, or be used by animation and web authoring tools, provided thus a very useful input for a wide range of scientists and practitioners.

5. CONCLUSIONS

Although the decrease in accuracy, using 3D BUILDER instead a strict photogrammetric procedure, may seem a lot, we should admit that, in absolute terms, it is quite adequate for everyday practice in close range applications, where accuracies of better than 1 cm is rarely required.

Moreover, solution No. 1 reveals that even in the absence of control point measurements (a rather usual practice in Architectural Photogrammetry) the achieved accuracy is quite acceptable for such applications.

However, besides the achieved accuracy, 3D BUILDER and other software of the same family, exhibit many other merits, since they heavily invest on adding-value to the photogrammetric product. The visualization tools they include are only met to high-end photogrammetric software.

In conclusion, 3D BULDER and the software of this kind should not be underestimated by the photogrammetric family, since their functionality is quite adequate for a range of close range applications. At the same time their output products fit very well the needs of the users, providing the necessary 3D models in a form they can understand and use thereafter.

BIBLIOGRAPHY

Boccardo, P., A., Lingua, F., Rinaudo, 1997. Low cost digital acquisition systems for Architectural Photogrammetry, IAPRS, Vol. XXXII, Part 5C1B, CIPA Intern. Symposium, Göteborg, Sweden, pp. 141-146.

Hanke, K., and M., Ebrahim, 1997a. Monument presentation using digital architectural Photogrammetry, IAPRS, Vol. XXXII, Part 5C1B, CIPA Intern. Symposium, Göteborg, Sweden, pp. 147-153.

Hanke, K., and M., Ebrahim, 1997b. A low cost 3-D measurement tool for architectural and archaeological applications, IAPRS, Vol. XXXII, Part 5C1B, CIPA Intern. Symposium, Göteborg, Sweden, pp. 113-120.

Patias, P. and G. Karras, 1995. Modern photogrammetric procedures in Architectural and Archaeological applications, Ziti Editions, Thessaloniki, Greece (in Greek).