EVALUATION OF A DIGITAL NON METRIC CAMERA (CANON D30) FOR THE PHOTOGRAMMETRIC RECORDING OF HISTORICAL BUILDINGS

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ABSTRACT:

This paper is about the evaluation of a digital non-metric reflex camera (Canon D30) for low cost applications in archaeology, architecture and cultural heritage. At present digital cameras of different geometric qualities are being routinely used for this purposes. The Canon D30 digital camera is a professional camera with a CMOS sensor of 3.2 Mp. Although camera resolution is relatively low, compared with more recent amateur cameras, the sensor is slightly smaller in size than conventional 35 mm film format. The focal length/angle of view conversion factor is approximately 1.6x compared to full frame 35 mm film format. This property makes very interesting the use of this camera in cultural heritage photogrammetric applications, where both accuracy and final image quality are quite important. The camera internal geometry has been solved by means of self calibration with own developed software. First self calibration was made at laboratory using digital target measurement at subpixel accuracy. Proportional accuracies with this method were between 1:20.000 and 1:30.000. But additional self calibrations where carried out with field control points. In this case, accuracy reached was poorest because images were manually measured on natural points, but it was for normal architectural/archaeological applications enough. As main drawback of this camera we can point out the low sensor resolution. So when camera/object distance increases or high oblique photographs are employed the image quality of the final product reduces considerably.

1. INTRODUCTION

Last decade has seen an extensive use of digital non metric compact cameras for use in low cost applications in archaeology, architecture and cultural heritage. The important rise in image resolution, the dropping prices, present facilities in storing/transferring images files and easy direct image acquisition (without digitising films or paper prints) are the main responsible for the attractive use of this instrumentation. Also the use of low cost digital photogrammetric systems (both stereoscopic and convergent stations, such as, for example, DVP®, ShapeCapture®, Photomodeler®, 3D Mapper®) has contributed to the use of these "off the shelf" cameras among photogrammetrist and non photogrammetrist.

These cameras have been routinely used for low cost applications, but only in cases where accuracy was not critical. Several reasons explain the loss of accuracy when these cameras are used. These cameras are designed mainly for the amateur market and not for photogrammetric purposes. Lenses are small and, in general, not of very good geometrical and optical qualities. Also usually they are auto focus zoom lenses (so high inner instability should be expected). Sensors (both CCD and CMOS types are usual) are much reduced in size than those of high quality digital cameras and than 35 mm film cameras. Sensor size is a very important drawback in the use of these compact cameras with metric purposes. Usually sensor sizes vary from 1/2.7" to 2/3". Even in the case of a high resolution sensor (some present "off the shelf" compact cameras reach 8 Mp) metric precision is not guaranteed. Besides, once cameras have been calibrated, inner parameters are not stables, so important space reconstruction errors can occur. Anyway, adequately calibrated, some of these cameras can reach subpixel accuracy (at least at laboratory conditions) and they can be suitable for archaeological applications (Ogleby et al, 1999).

In this paper, a digital single lens reflex (SLR) camera, Canon D30 (Figure 1), is analysed for its use in archaeology and architecture. But the scope of this analysis goes to explore the metric applications not only in low accuracy and fast applications but also in medium precision works with conventional data reduction instrumentation (stereo plotters).

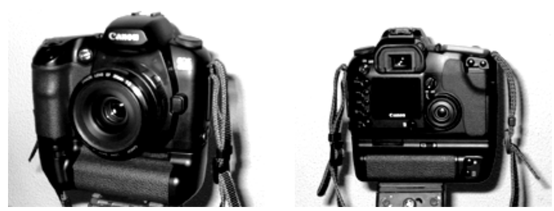

Figure 1. Canon EOS D30 SLR digital camera with battery grip

2. THE CANON EOS D30 CAMERA

The image pick-up device used in the EOS D30 is a 3.25 million pixels complementary metal oxide semiconductor (CMOS) sensor with noise reduction functions. Total pixels are 2226 x 1460, but effective pixels are 2160 x 1440. The sensor size is 15.1 x 22.7 mm (aspect ratio 2:3), so it is slightly smaller than conventional 35 mm film camera format (Figure 2). Files can be recorded in RAW and JPEG (with two compression levels) formats. The recording media is a CF (Compact Flash) card, type I or II. The sensitivity is equivalent to ISO 100-1600. The camera has the usual features (manual and several automatic exposition modes, different metering systems, continuous shooting at 3 high quality JPEG images/second, seven white balance modes, built-in flash, etc.) of present SLR digital cameras. An important aspect is that the camera has a Canon EF mount, so normal Canon EF lenses (and compatible ones) can be used. The focal lenght/angle of view conversion factor is approximately 1.6x compared to full-frame 35mm film format. Finally, it is necessary indicate that at the time the abstract of this paper was submitted (September. 2003), the camera has been updated by some higher models with a similar CMOS sensor but at 6 Mp (Canon, 2004).

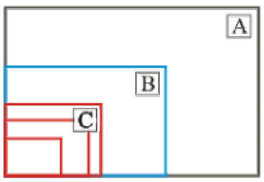

Figure 2. Sensor size comparison. A: 35mm film format and present high quality digital reflex cameras. B: Canon D30 CMOS sensor size. C: Three typical CCD sensor sizes in conventional “off the shelf” digital cameras (1/2.7”, 1/1.8” and 2/3”)

3. CALIBRATION

3.1 Lenses used

Two lenses were available for the camera: Sigma 20 mm 1:1.8 EX DG aspherical lens; and a Canon EF 35 mm 1:2 lens. Because the conversion factor to full-frame 35mm film format (1.6x), the equivalent focal lengths are 32 mm (wide angle) and 56 mm (normal), respectively. Both lenses were calibrated at laboratory conditions. Because workspace at laboratory was limited, exposure mode was manual in order to select an f-stop setting suitable for a good depth of field with the camera focused at infinity. Focus rings were fixed with adhesive tape to maintain the inner orientation as stable as possible.

3.2 Calibration procedure

The camera with the two lenses was calibrated by means of self calibration (Fryer, 1992) by adjusting blocks of convergent photographs of a targeted test range (Figure 3). The test range consisted in 35 white circular retro-targets fixed at a wall and 10 additional targets at different depths.

Each lens was calibrated with two epochs of 6 convergent photographs (12 photographs per lens). As usual in close range photogrammetry shots with 90º rolls were taken.

Targets were illuminated with the built-in flash in the 35 mm lens, but it was necessary an external flash unit for the 20 mm lens to avoid vignetting because the large lens size.

The target photo-coordinate measurements were made by means of a routine programmed by the authors under I.D.L.® 5.2. This program locates and computes the centroids of the targets and it is based on the optimum binarization threshold of the elliptical targets (after Trinder et al, 1995).

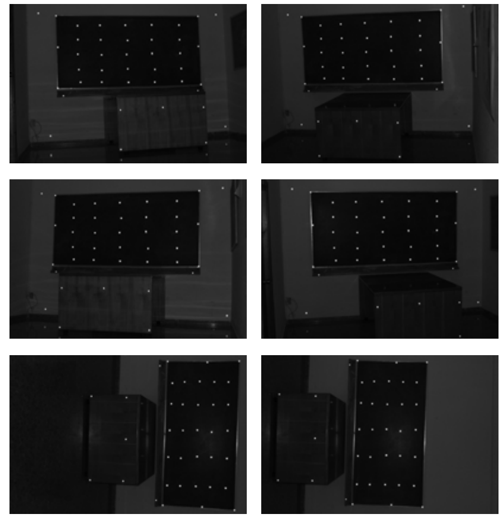

Figure 3. Retro-targets in the test range. Block of 6 convergent photographs taken with the Canon D30 and Canon 35 mm lens.

Self calibration was solved by means of a routine programmed under I.D.L.® 5.2. It was a free net adjustment by minimal inner constraints, without any external surveyed control point. The mathematical model is shown in equation 1:

$$\begin{vmatrix} \dot{B}^T W \dot{B} & \dot{B}^T W \ddot{B} & \dot{B}^T W \dddot{B} & 0 \\ & \ddot{B}^T W \ddot{B} & \ddot{B}^T W \dddot{B} & G^T \\ & & \dddot{B}^T W \dddot{B} & 0 \\ & \text{symmetric} & & 0 \end{vmatrix} \begin{vmatrix} \dot{\Delta} \\ \ddot{\Delta} \\ \dddot{\Delta} \\ k \end{vmatrix} = \begin{vmatrix} \dot{B}^T W \varepsilon \\ \ddot{B}^T W \varepsilon \\ \dddot{B}^T W \varepsilon \\ 0 \end{vmatrix} \qquad (1)$$

where:
B: design matrices (after linearization of collinearity equations)
Δ: unknown corrections
W: the photocoordinate weight matrix
ε: discrepancy vector.
G: Helmert matrix
k: 7x1 vector of lagrangian multipliers

Matrices quoted with one dot (·) are related with outer parameters, (··) object point coordinates and (···) inner parameters. Since network is free, the rank deficiency of normal equation matrix is overcome by the use of the seven constrained equations grouped in the G matrix (Atkinson, 1996).

3.3 Calibration results

Self calibration was applied using a block invariant model (Fryer, 1992). The adjusted inner parameters were the principal distance (c), principal point offset (x_0, y_0) and the first and second radial symmetric distortion coefficients (K_1, K_2). The first one, K_1, was enough for the Canon 35 mm lens, while distortion in the Sigma 20 mm lens was better reproduced by both K_1 and K_2 coefficients. Our previous experiences have shown that others higher order and decentering distortion coefficients were not significant for the tested lenses. Affine parameters or other additional parameters were not taken into account. Table 1 shows the result of the self calibration for both lenses.

Sigma 20 mm		σ
C	20.7944 mm	±0.0064 mm
x_o	0.2255 mm	±0.0115 mm
y_o	-0.0954 mm	±0.0092 mm
K_1	-2.51E-04 mm^{-1}	±4.24E-06 mm^{-1}
K_2	5.49E-07 mm^{-3}	±2.56E-08 mm^{-3}
rms_{xy}	0.091 mm	
rms_z	0.159 mm	
Prop. error XY	1:27000	
Prop. error Z	1:15000	

Canon 35 mm		σ
C	35.3578 mm	±0.0143 mm
x_o	0.1694 mm	±0.0031 mm
y_o	-0.0425 mm	±0.0034 mm
K_1	-6.44E-05 mm^{-1}	±3.42E-07 mm^{-1}
rms_{xy}	0.199 mm	
rms_z	0.463 mm	
Prop. error XY	1:20000	
Prop. error Z	1:9000	

Table 1. Results of self calibration of the Sigma 20 mm and Canon 35 mm lenses.

The root mean square errors (rms) in planimetry (rms_{xy}) and depth (rms_z) are also expressed in Table 1. These errors (in object space coordinates) have been obtained from comparison on 35 target points from the two epochs. The largest distance in object space (defined by the targets) has been compared with the errors and the proportional accuracies (rms per distance), both in planimetry and depth, are given. Better accuracy has been obtained with the 20 mm lens (near 1:30000 in planimetry). This can be explained as consequence of the network configuration. In the 20 mm lens network, the object-camera distance was around 2 m (adequate depth of field was attained at that distance) and the network had a strong convergent geometry. While, in the 35 mm lens network the average object-camera distance was 5.5 m and the convergent geometry was less strong than in the 20 mm case. Probably a better network configuration in a wider workspace had improved these results (see Atkinson, 1996, for a detailed revision of network design and optimization).

These results indicate a good response of the tested camera and lenses for metric applications in archaeology and architecture, even in medium accuracy works. But it is necessary to check out if the inner parameters are representative in field conditions and at other object-camera distances, although with lens focused to infinity. Calibrations were made at laboratory conditions with retro targets and digital measurement techniques (at subpixel accuracy). They are not usual work conditions in cultural heritage projects, unless in case of special works (wall deformations, high precision measurements, etc.). Also convergent network have been used. Maybe in case of using stereopairs, the weak geometry is not enough to compensate for systematic errors that remain unsolved.

4. CANON D30 IN HERITAGE PROJECTS

4.1 Introduction

The Canon D30 camera can be used for documentation in general cultural heritage projects just like any digital or analogue camera. The reduced resolution (3.2 Mp) is the main drawback of this camera. In our own experience (with the tested lenses in this paper) when camera-object distance increases above 15 m, lack of image resolution appears.

An example is shown in Figure 4, which illustrates an Almohade watchtower (XII[th] century) exceptionally well preserved since the construction material is mainly mud (cob wall) and there are rests of the original battlements (Orcera, Spain). Figure 4 includes photographs of the tower walls and the WRML model of the tower. At the time of the publication of this work, the tower will be being restoring.

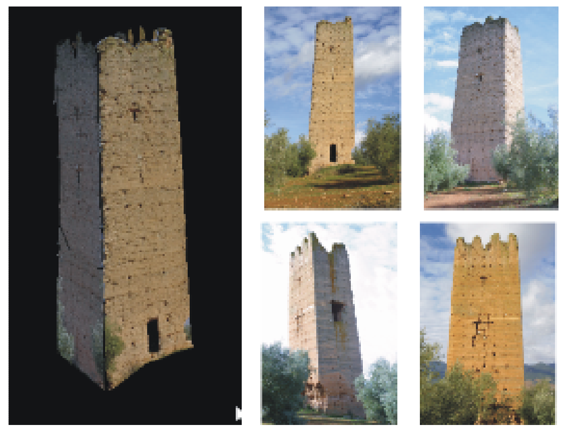

Figure 4. Photorealistic WRML model of an Almohade watchtower (XII[th] century) in Orcera (Spain). Photos taken with Canon D30 with 35mm lens.

But this camera can be used with metric purposes as it is shown by Mata et al (this volume). The Canon D30 camera has been used in combination with other camera types (metric, semi-metric and non metric analogue cameras) in a complete photogrammetric documentation project for the restoration of the St. Domingo de Silos' Church (XIV[th] century) in Spain (UJA, 2003).In next sections some examples are given in order to show the possibilities of using this camera in real field works.

4.2 Study of a rib vault and walls in a restoration project

4.2.1 Vault. First example is the study of a rib vault in the St. Domingo de Silos Church (Mata et al, this volume). The vault covers the main chapel of the church (Figure 5). It has an asymmetrical plan (between rectangular and trapezoidal) of 6 x 7 m and a height between 3.5 m (at the rib springing) and 7 m.

Zenithal shots were made from the ground organised in three strips with the 20 mm lens (Figure 6). Projection centers were separated 1.5 m (in the same strip) and the strip axes were approximately separated 3 m. That configuration allowed high end and side laps (80% and 25-45%, respectively) in order to minimize the relief displacement in the images because one of the objectives was an orthophotograph (Figure 5).

Control, check and pass points were manually measured in the images with ENVI©. Phototriangulation was carried out with a routine developed under IDL©.

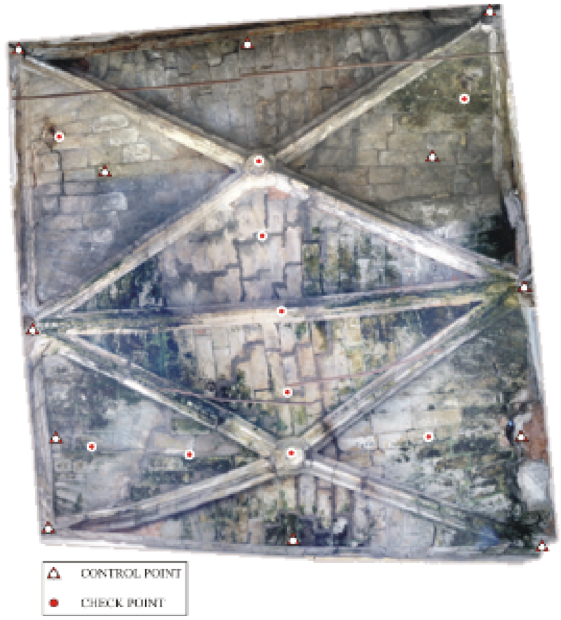

Figure 5. Ortophotograph (3 mm GSD) of the rib vault of St. Domingo de Silos' Church (XIV[th] century, Spain). Control and check point networks are shown.

Final results are shown in Table 2. Table 2A contains the errors in planimetry (XY) and depth (Z) when the camera Canon is considered as calibrated and the inner parameters obtained in laboratory (Table 1) are fixed. The table also expresses the proportional errors in XY (rms_{XY} with respect to the vault diagonal, 9.3 m) and Z (rms_Z with respect to the mean object-camera distance, approximately 6.5 m). Table 2 shows very promising results about the accuracy obtained (errors, expressed as rms, below $\pm$6 mm).

In order to check out any improvement in the results, a field self calibration was run and new inner parameters were computed. As can be seen in Table 2B, the results were improved, in particular the Z (depth) coordinate. Thus, while the accuracy in XY improved only 12 %, there was an important improvement of accuracy in Z of 40%.

VAULT	A	B
Rms XY	$\pm$ 5.1 mm	$\pm$ 4.5 mm
Max. Vxy (abs.)	7.9 mm	6.1 mm
Rms Z	$\pm$ 6.0 mm	$\pm$ 3.5 mm
Max Vz (abs.)	11.9 mm	6.0 mm
Prop. Error (XY)	1:1800	1:2100
Prop. Error (Z)	1:1100	1:1850

Table 2. Vault case. A: root mean square (rms) and proportional errors in planimetry (XY) and depth (Z) at check points with the camera calibrated at laboratory (inner data in table 1). Maximum residuals in XY and Z (in absolute values) are also expressed. B: rms and proportional errors in (XY) and (Z) at check points after field self calibration.

Although the photographs were not convergent (in fact they were parallel shots), relatively good conditions to apply self calibration occurred: large depth differences in the object (between 3.5 to 7 m); high overlapping photographs; high redundancy; and the measured points (control, check and pass points) were well distributed in all frames.

Finally, inner parameters were imported in a DPW (Socet Set© v.4.4.2) and a DSM and ortophotograph were produced. Cross sections were derived from the DSM and the vault deformation was analysed (see Mata et al., this volume).

4.2.2 Wall. Next example illustrates the photogrammetric survey of a side wall in the nave of St. Domingo de Silos' Church (Figure 7). Some stereopairs were taken. Two additional convergent shots were made to complete the final mosaic of rectified images, because there were hidden areas behind the pillars of the nave arches.

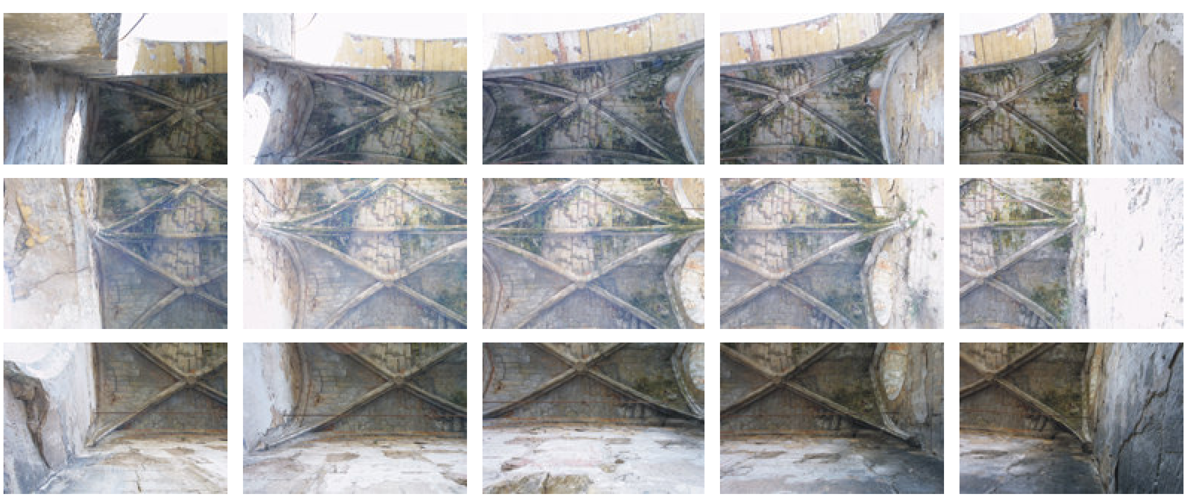

Figure 6. Block of zenithal photographs (Canon D30 with Sigma 20 mm lens) in the vault of St. Domingo de Silos' Church.

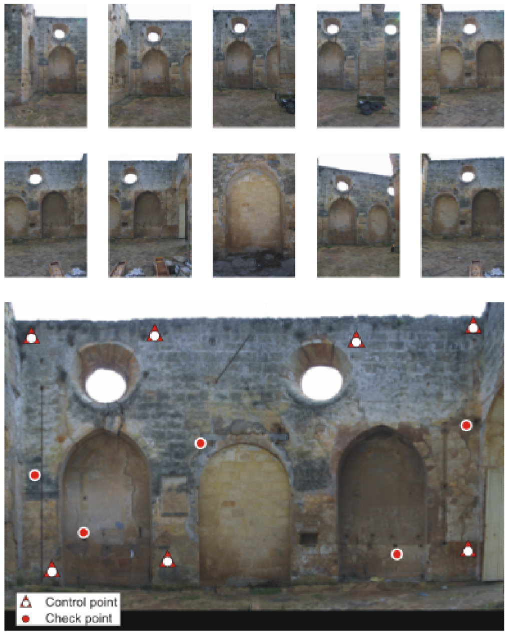

Figure 7 Mosaic of rectified photographs in the wall of the nave of St. Domingo de Silos' Church (4mm GSD). Photographs taken with the 20 mm lens are also shown. Control and check point network is displayed.

In this case, only one strip (10 parallel photographs plus two convergent ones) was processed. Camera stations were at 9.5 m, as average, from the wall and the bases were 1-1.2 m, so the B/D ratios were near to 1/10.

WALL	A	B
rms XY	± 5.6 mm	± 5.2 mm
max. Vxy (abs.)	6.9 mm	6.4 mm
rms Z	± 7.9 mm	± 7.1 mm
max Vz (abs.)	12.3 mm	13.8 mm
Prop. Error (XY)	1:2500	1:2650
Prop. Error (Z)	1:1200	1:1400

Table 3 Wall case. A: rms and proportional errors in planimetry (XY) and depth (Z) at check points with the camera pre-calibrated. Maximum residuals in XY and Z (in absolute values) are also expressed. B: rms and proportional errors in (XY) and (Z) at check points after field self calibration.

Control, check and pass points were measured and, then, the strip triangulation was processed considering the camera calibrated at the laboratory conditions. Next, a new run with self calibration was carried out and inner parameters were also adjusted. The results are displayed in Table 3. In this table, the proportional errors in XY and Z are also expressed as rms_{XY} with respect to largest distance in the wall (approximately 14 m) and rms_Z with respect to the camera-object distance (9.5 m).

In case A (Table 3A) with the camera calibrated at laboratory, accuracy was similar to that of the vault case (mean errors below ±8 mm). But, the field self calibration did not improve meaningfully the accuracy, just nearly 10 % in both XY and Z (Table 3B). In any case the final results met the accuracy requirements (± 3 cm in coordinates and a final plotting scale of 1:50). Probably, the photogrammetric network in this case was not strong enough to solve adequately the self calibration.

4.3 Comparison of UMK stereopairs and analytical plotter with Canon D30 in the study of a façade

Finally, another usual situation in architectural photogrammetry has been tested. In this case, single Canon D30 stereopairs have been oriented and the results have been compared to those obtained with a metric camera (UMK 1318/10) and analytical stereoplotter (Leica SD-2000), (Figure 8).

Figure 8 Two UMK 1318/10 stereopairs (above) and two Canon D30, with 20 mm lens (below), in the façade of St. Domingo de Silos' Church.

The church façade was photographed with the UMK and two stereopairs were taken. Usual 1/5 B/D ratios were employed and the photo scales were approximately 1:100. The orientations were made with 12 parallax points per model (distributed as usual in six areas), 4 control points per model and a total of 8 check points. Table 4 displays a resume of the accuracy obtained in both UMK stereopairs. Errors are better than ± 5 mm. These errors were the expected with these data acquisition and reduction methods since the control point were well defined but natural points. The orientation errors with the Canon D30 were compared with these data.

Stereopairs with the Canon D30 were taken with same conditions. All points were manually measured and a bundle adjustment was performed. But orientations were computed in six different ways. First, the models were solved same as the UMK stereo pairs by using the field control points (Canon D30 CP in Table 4). Although accuracy has been poorer than in the UMK case (as expected), good results were obtained with mean errors better than ± 1 cm. In this case the camera was considered as calibrated (with data of Table 1) since self calibration was not possible in single stereopairs.

A second choice was selected since it is usual the lack of control points in fast and low cost surveys. In this case stereopairs were oriented with a known distance (DIST in Table 4) and three selected points for datum definition (Atkinson, 1996).

FAÇADE	UMK	CANON D30					
	CP	CP	DIST	A (CP)	A(DIST)	B (CP)	B (DIST)
rms XY (mm)	± 2.7	± 5.9	± 12.0	± 64.9	± 77.0	± 54.9	± 66.9
rms Z (mm)	± 3.4	± 9.9	± 16.8	± 57.9	± 105.0	± 58.6	± 112.6
max Vxy (abs) (mm)	3.0	7.9	14.2	85.3	93.8	74.2	82.5
max Vz (abs) (mm)	5.0	14.5	26.9	85.6	208.4	82.2	-224.5
Prop.accuracy XY	1:5700	1:2600	1:1300	1:250	1:200	1:275	1:225
Prop.accuracy Z	1:3200	1:1200	1:700	1:200	1:110	1:200	1:100

Table 4 Façade case: rms errors, maximum residuals (in absolute values) and proportional accuracies in XY and Z for different situations. **UMK**: stereopairs oriented with control points (**CP**); **Canon D30**: stereopairs oriented with **CP**; known distance (**DIST**); **A**: stereopairs oriented with **CP** and **DIST** (only calibrated principal distance is used); **B**: stereopairs oriented with **CP** and **DIST** (no camera calibration).

Again the camera was considered as calibrated, but, since control point and convergent photographs were not used, systematic errors have been propagated to object space and the accuracy has decreased almost 50 % (mean and maximum errors of ± 1.5 cm and ± 3 cm, respectively).

Finally, other situations were explored. In the case A (Table 4) only principal distance was known (distortion and principal point offset were neglected). This option was selected because principal distance is easy to be calibrated, even with graphical methods. But in case B any calibrated inner parameter were considered (the principal distance was the nominal focal length, 20 mm). In both cases, A and B, orientations were carried out with control points (CP) and a known distance (DIST). In the four situations (Table 4) the results were very weak (with maximum errors higher than ± 20 cm), with slight better results in the case of using control points (as expected). There were not meaningful differences in calibrate only the focal length or not calibrate at all. In stereopairs, errors in the focal length can be partially compensate with changes in the projection center, so it is an error source less critical than distortion in this lens type or other systematic errors present in non metric cameras.

5. CONCLUSIONS

As conclusion, the Canon D30 camera has revealed to be an effective data acquisition system for low and medium precision works in archaeological and architectural surveys. The test with wide angle and normal lenses have shown that camera calibration at laboratory and the use of control points can minimize the systematic errors present in non metric cameras when stereopairs are used. If the photogrammetric network is appropriate a field self calibration can improve the final accuracy. The experiences have shown that errors between 5-10 mm can be reached at object-camera distances up to 15 m. (longer distances have not been tested) even in the case of single stereopairs. So the Canon D30 can be used for conventional architectural and archaeological surveys including stereoplotting, DSM, ortophotographs, rectified images, 3D modeling, but also control point network densification. Future work will be focusing in test some improvement with self calibration and additional parameters, tests at longer distances and the evaluation of similar present digital cameras with higher resolution.

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