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Calibration of a Photogrammetric System for Semiautomatic Measurement: CaM-DisT®

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Abstract. Nowadays some measurement tasks are usually made by the joint use of different systems, techniques, even sciences, trying to find the best results together with less work time. This is the case of close range photogrammetry and laser distancemeter. It is possible to find some works where they are applied together in so different sceneries as architectonic conservation, civil engineering, building, etc. One of the scopes where these techniques can be applied is in the measurement of facades of buildings in construction [1,2]. During the constructive process it is necessary to make periodic measurements, and also during the whole life of the building, as a control tool [3]. At the present day some of these measurements are hand-made, with the risk of having an industrial accidents in some situations. In this work we present a methodology based on a photogrammetric - distancemeter joining measure system, in order to semi-automate some measurement procedures in building construction. The system consists of a semi-rigid calibrated support putting up a laser distancemeter and a digital camera, called CaM-DisT®. The support was specifically designed for this kind of application. The development of the system was made in four steps: establishment of the mathematical background; design of the support; construction of the support; and calibration of the complete system. The calibration process was made by two different alternatives which are xpounded this contribution in detail.

Introduction

One main advantage of photogrammetry is its ability to obtain metric data from non-contact measurements. This is a very useful aspect in the field of building construction, where it is usual to take measurements by mean of direct methods, such as tape measure. Replacing in-situ methods with close-range photogrammetry has some other obvious advantages but, for success, it would be necessary to apply low-cost and easy-to-use photogrammetric methods, in order to be used by non-specialist.

Low-cost close-range photogrammetry techniques have been studied by some researches and engineers [4]. They are based on the use of low-cost digital cameras, doing the field-work without support of topographic equipment for control point measure [5]. Some researchers have designed their own tools to replace topography support. Tomasseli and Lopes [6] propose a photogrammetric system based on the joint use of a digital camera and a laser distancemeter for determining the dimensions of flat surfaces, such as billboards, using just one picture. The distance between the camera and the surface is measured using the lasermeter, providing the coordinates of the camera perspective centre.

In this work, we present a system called CaM-DisT® (Fig. 1) which has been designed and built for us. The main characteristics of CaM-DisT® are: 1) small size and low weight, 2) full compatibility with all cameras and distancemeters, 3) rigid joint between camera and distancemeter, but allowing vertical and horizontal movements between them ensuring repeatability.

A very important topic is the calibration of these equipments. It is usual to find calibration techniques of different apparatus applied to very disparate areas within the field of engineering. The calibration of a multiple system is based on knowing the relative parameters between the actual components. The system depends on the precision of these parameters. It is therefore necessary to know exactly what the relative position is between the components that they consist of and the convergence or divergence that their respective construction axis display. Diverse reverse engineering techniques may be used to do this, based on mathematical processes applied to the calibration with objects of a known size. Van den Heubel [8] is studied the 3D reconstruction objects from a single image using geometric constraints. Haralick [9] a similar procedure is proposed for determining the camera inner parameters by using a picture with undefined scale, just a distance value in the object space printed in it.

In this case the different ways to calibrate a system will be studied, the components of which are linked in a rigid support of unknown dimensions. In order to do so, it will be necessary to use a calibrated panel or net thus solving the problem using direct or indirect methods as to where the positioning of the coordinate system is found.

Calibration Set Up: determining Unknown Factors

The system consists of a rigid support to which a laser distancemeter and a digital camera are attached, as shown in the figure below (Fig. 1). The objective is to know (Fig. 2):

1. The relative position between the camera's optical centre and the fixed point of origin of the laser distancemeter.
2. The angular components between the camera's optical axis and the fixed axis of the laser distancemeter.

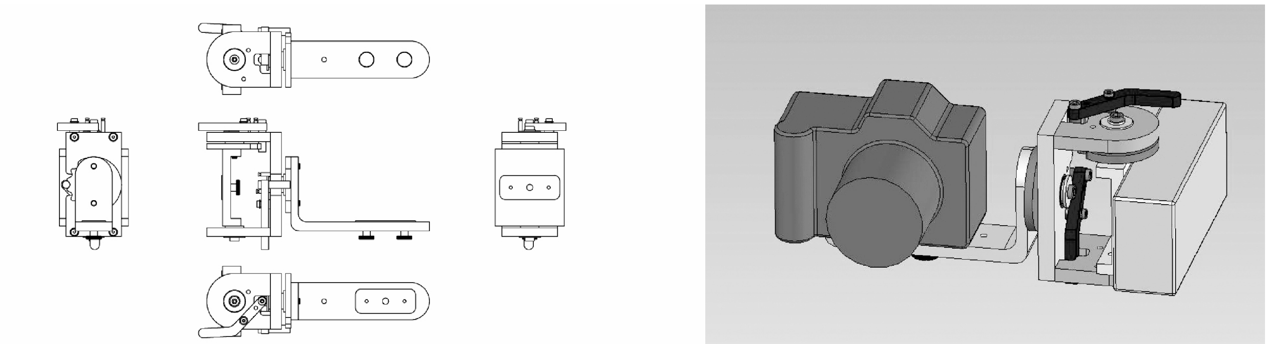

Fig.1 Plan of the CaM-DisT® complete system formed by the camera and the distancemeter joined by the rigid support

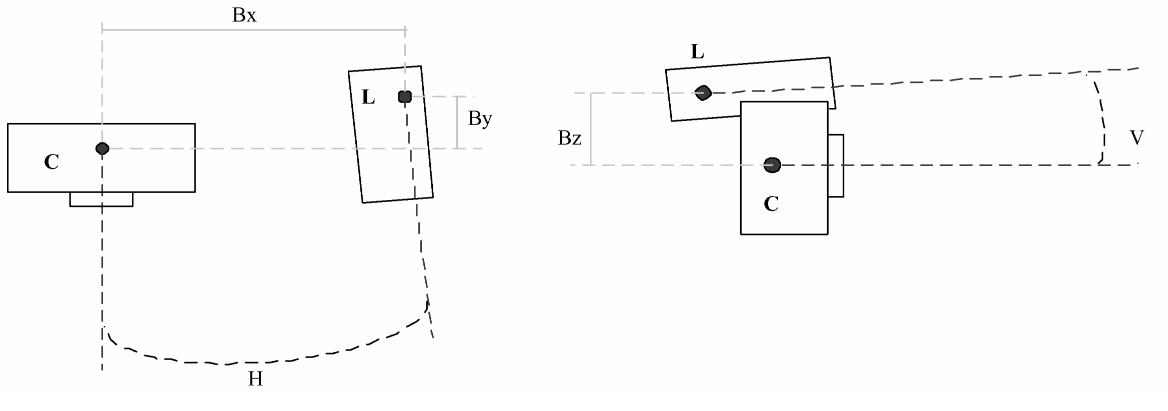

Fig.2 Top view (left) and left view (right) of the system CaM-DisT®

where, (X_C, Y_C, Z_C) are coordinates of the optical centre of the camera, (X_L, Y_L, Z_L) are coordinates of the fixed point of origin of the laser distancemeter, (B_X, B_Y, B_Z) are components of the base between the optical centre of the camera and the fixed point of origin of the laser distancemeter, (V, H) are angular components between the optical axis of the camera and the fixed axis of the laser distancemeter (the camera used was calibrated and all elements are fixed and immovable).

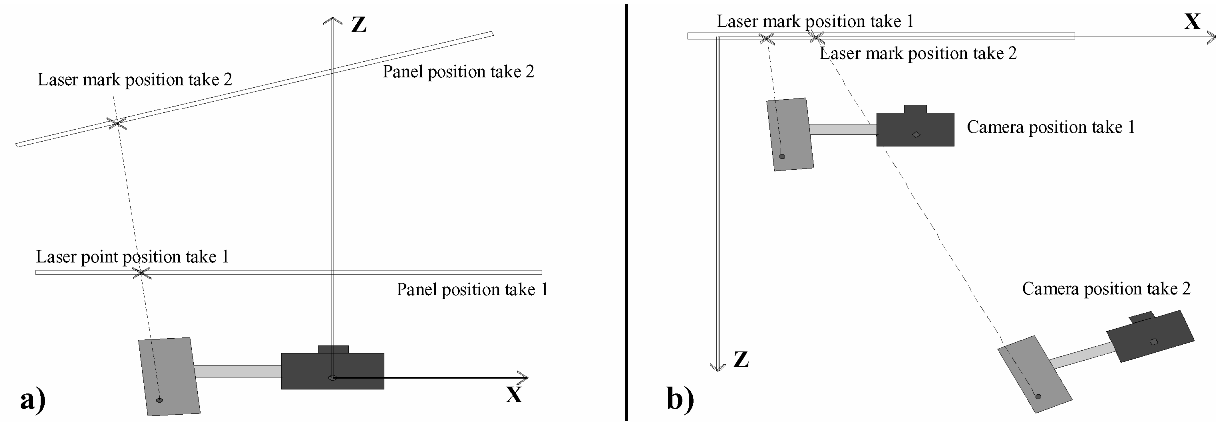

Fig.3 a) Plan of the calibration process with the system of coordinates on the camera.
b) Plan of the calibration process with the coordinates system on the panel

To make possible the objectives, a method has to be designed that can calculate the position of two different points on a trajectory. The most precise definition of the centre will be obtained if one of the points is as close as it possibly is to the entry point. The most precise definition of the vector will be obtained if one of the points is as far as it can possibly be to the entry point. As each photo is taken, a distance measurement will be made, ensuring that the position of the laser mark appears in the photographic image.

Mathematical Process of Calibration

At the first time, we defined the characteristics of the photographic camera, mainly the aberrations of the lens (focal length, main point, radial and tangential distortion) [10].

Regardless of the calibration process, the method for data collection does not change. In fact the system of coordinates can be placed either on the camera or on a known point on the net, as it makes no difference. It needs to be pointed out, though, that the movement between the two objects is always relative, so by moving the net and keeping the position of the camera fixed and stationary the same result is achieved by moving the camera while the net remains in a fixed position. The difference between the calibration models will be the point in which the origin of the coordinates system is fixed. The possible variances are:

Method 1: Taking photographs and laser measurements using a calibrated panel, from two different positions, with the coordinates system fixed on the camera (Fig. 3 a). Supposing the two images have been captured and that in the two photos the position of the laser mark appears inside or outside of the rectangular space defined by the photographed panel (this can be the calibration net or a simple rectangle of a certain size). The four corners of the rectangle and the laser point coordinates will be measured to ascertain their position in the photograph. The distance will also be measured from the entry point to the panel. The positioning of both shots (by camera and laser) using the coordinate system that is fixed on the camera is shown in Fig. 3.

The coordinate system will be orientated so that the Z axis is in the direction of the take and the X and Y axis are perpendicular to the main direction of the shot. As is widely known, the photogrammetry Eq.11 is, Eq. 1:

$$Xt - Xo = (Zt - Zo)\frac{m_{11} * x + m_{12} * y - m_{13} * f}{m_{31} * x + m_{32} * y - m_{33} * f}; Yt - Yo = (Zt - Zo)\frac{m_{21} * x + m_{22} * y - m_{23} * f}{m_{31} * x + m_{32} * y - m_{33} * f} \tag{1}$$

where (X_t, Y_t, Z_t), are coordinates of the corners of the net; (X_o, Y_o, Z_o), are coordinates of the camera; (x, y), are photo-coordinates; f, is main calibrated distance; m_{nn}, are rotations in X, Y and

Z. Given that camera rotations are nil and their coordinates are also nil, the aforesaid equations can be rewritten as (Eq. 2):

$$Xt = Zt\frac{x}{f}; Yt = Zt\frac{y}{f} \quad (2)$$

The coordinates of the panel corners are unknown although the geometry and dimensions are known. Using this knowledge, and by labelling the upper left hand corner of the rectangle (X_r,Y_r,Z_r), it can be found that there are two unit vectors in the direction of the two rectangular sides V_1 (1, 0, 0) and V_2 (0 , 1, 0) which rotated in the space with any rotation of type (α, β, γ) and with a translation (X_r, Y_r, Z_r) positions the vectors, knowing already the longitude of the two known sides, L_1 and L_2 as we do. There are therefore 6 unknown values (X_r, Y_r, Z_r) and (α, β, γ) that make up the coordinates of the 4 corners of the rectangle. If V_{1r} is the result of turning vector V_1 and V_{2r} is the result of turning V_2, according to Eq. 3:

$$V_{1r} = [R] * V_1; V_{2r} = [R] * V_2 \quad (3)$$

where [R] is the rotation matrix, as result of the rotations in R_α, R_β and R_γ. Then the coordinates of the four corners, as we can see in Eq. 4, are:

$$\begin{aligned}&(X_r, Y_r, Z_r); (X_r, Y_r, Z_r) + V_{1r} * L_1;\\&(X_r, Y_r, Z_r) + V_{2r} * L_2; (X_r, Y_r, Z_r) + V_{1r} * L_1 + V_{2r} * L_2\end{aligned} \quad (4)$$

where L_1 y L_2 are equal to the lengths of the rectangle. For each corner it is proposed that the two equations for taking shots are used, resulting in the 6 unknown values. The calculation of the laser mark position is obtained by intersection of the photogrammetric beam with the plane of the wall. The position of the laser will be (Eq. 5):

$$(X_p, Y_p, Z_p) = (X_r, Y_r, Z_r) + a * V_{1r} + b * V_{2r} \quad (5)$$

Its position will be obtained by posing the photogrammetry equations for this point obtaining a system of two equations with two unknown values *a* and *b*, both of which are determined and lineal. In addition, the redundancies in the calculations can be increased by imposing the same conditions regarding planes between the panel corners and the laser mark, given that three points form a plane in which the other two points can be found with every shot taken. Therefore a redundant mathematical process is formed by: Data (coordinates and turns of the camera, five pairs of photo-coordinates in each shot, the laser distance measurement of each shot, known sides of rectangle: L_1, L_2); Unknown values (four spatial positions of the panel corners in each shot, determined by X_r, Y_r, Z_r and α, β, γ, and a spatial position of the laser mark in each shot, determined by *a* and *b*.

Method 2: The coordinates system is established on the wall, with the origin of the coordinates in the top left of the rectangle (Fig. 3 b). Supposing again that the two photos have been taken and in the two photos the laser mark appears inside or outside of the rectangular space that was previously outlined, and the distance measurement is also taken in both shots. In this case the origin of the coordinates is situated in the panel, so it is the camera that has undergone relative movement in respect to the origin. In this case the four corners of the rectangle located in the coordinates system in the upper left hand corner are data, upper left hand corner (0, 0, 0), upper right hand corner (L_1, 0, 0), lower left hand corner (0, L_2, 0), lower right hand corner (L_1, L_2, 0), where L_1 y L_2 are equal to the lengths of the rectangle. The corresponding photo-coordinates measures in both shots will also be known values, as well as the photo-coordinates of the two laser mark positions in the respective shots. The unknown values in this instance will be the optical centre of the camera and the angular rotations of its optical axis in each take: (X_o, Y_o, Z_o) and (ω, φ, χ).

Turning once again to the photogrammetry equations (Eq. 1) that give a redundant mathematical system corresponding to the posing of four pairs of equations (one for each corner of the rectangle) with six unknown values in each, the position and the camera turns in each shot will be extracted easily. Calculating the laser mark position is again obtained directly from the intersection of the photogrammetric beam with the panel. Its position will be obtained by posing the photogrammetry equations (Eq. 1) for this point obtaining a system of two equations with two unknown values that are determined, definite and lineal.

Having arrived at this point, the next objective is to move the coordinate system to one of the cameras and to carry out a 3D transformation suitable for moving the camera from the second position to the first. By doing this, what is obtained is a theoretical movement of the panel with the two shots, from a fixed theoretical position, and then returning to the previous approach, the difference now is that all the parameters are known. Finally, for each shot the previous steps create eight equations for the rectangle and two for the laser mark in all instances. The final result found therefore for both cases is obtained from the following form: *Determining the vector is as easy as deducting the points obtained in the photos and obtaining a unit vector in that direction. Determining the point of origin of the laser measurement once the vector as nown is carried out by deducting the distance measured by the vector from any of the laser marks on the panel.*

Once the positions of the centres of the camera and laser are known, the components of the base can be easily obtained (B_x, B_y, B_z) like the components between both axes (V, H). Ensuring that both measures are coherent involves checking the coordinates of the distance from the entry point to each one of the points. If this check is desired (external condition) to form a part of the equation system, an additional distance equation and an additional equation of coplanarity can be added to the mathematical process, for each photo, that would check the distance measurement since the laser mark is found on the photographed panel.

Results

After calibration of CaM-DisT® with both methods it is possible to point out its stability not only mechanical but also dimensional. The differences detected in the results after some test were negligible. It is possible to state that the mechanical adjusts between the parts of the system are stables and satisfactory. Table 1 includes the calibration results obtained in two of its positions.

Table 1. Calculate values of the laser centre and direction in different positions

	X_L [m]	Y_L [m]	Z_L [m]	H [rds]	V [rds]
Axis are close to be in parallel position	-0.21049 ± 0.001018	+0.00432 ± 0.000065	+0.14562 ± 0.001233	-0.04703 ± 0.000229	-0.03147 ± 0.021300
Axis are in convergent position	-0.23461 ± 0.000154	+0.00050 ± 0.000098	+0.14106 ± 0.000546	+0.34891 ± 0.000152	-0.01685 ± 0.000093

If we analyze the results obtained, we can see (in the first case) maximum errors close to 1 mm in the *Z* axe, in the relative position between the camera's optical centre and the fixed point of origin of the laser distancemeter. In the angular components between the camera's optical axis and the fixed axis of the laser distancemeter, we can see a maximum error in the *V* angle. These errors suggest the presence of technical problems fastening the distancemeter to CaM-DisT®, due to the position over the distancemeter of the fastening screw which make possible turning on V direction. This fault will be reduced in the final CaM-DisT® design.

Conclusion

It is possible to conclude that CaM-DisT® complies with the initial requirements requested of the system. It is a stable and easy-to-use tool which can be operated by non-expert operator. However it will be necessary to correct some aspects of its final design before manufacturing, in order to minimize the errors detected in the calibration parameters.

Given the feasibility of both mathematic procedures have been demonstrated, several conclusions might be inferred which show the advantages of them both. However, they do differ in an essential factor, meaning that the second method becomes the best option.

According to the first exposure procedure, equations reflecting the geometry of the object might be established to obtain the final mathematic solution. This means that the calibration mesh should be built in a known geometry and should have no building errors. This might be in this way since rectangularity and scale conditions are imposed considering that there are no deformations or angular errors. In the second method this task lacks importance. Only the coordinates of at least 4 ground points need to be precisely determined, whatever their geometry. This is an important difference, since it means that the second method might be applied in a wider range of cases.

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References

[1] R.A. Dick, P.H.S. Torr and R. Cipolla: International Journal of Computer Vision Vol. 60 (2) (2004), p. 111.

[2] J. Mills and D. Barber: Journal of Surveying Engineering Vol. 130 (2) (2004), p. 56.

[3] P. Arias, J. Herráez, H. Lorenzo and C. Ordóñez: Computers & Structures Vol. 83 (21-22) (2005), p. 1754.

[4] J.H. Chandler, J.G. Fryer and A.C. Jack: Photogrammetric Record Vol. 20 (109) (2005), p. 12.

[5] P. Arias, C. Ordóñez, H. Lorenzo and J. Herráez: Survey Review Vol. 38 (300) (2006), p. 525.

[6] A.M. Tommaselli and M.L. Lopes: Photogrammetric Engineering & Remote Sensing Vol. 71 (6) (2005), p. 727.

[7] P. Arias, H. Lorenzo and C. Ordóñez, Spain Patent P200,600,770 (2006).

[8] F.A. Van den Heuvel: ISPRS Journal of Photogrammetry and Remote Sensing Vol. 53 (1998), p. 354.

[9] R.M. Haralick: Pattern Recognition Vol. 22 (3) (1989), p. 225.

[10] J.G. Fryer, in: Close Range Photogrammetry and Machine Vision, edited by K.B. Atkinson Whittles Publishing, Caithness, UK (2001).

[11] P. R. Wolf and B. A. Dewitt: Elements of Photogrammetry with Applications in GIS (2000)