CALIBRATION OF A PHOTOGRAMMETRIC SYSTEM FOR SEMIAUTOMATIC MEASUREMENT.

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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 the less work time. This is the case of close range photogrammetry and topographic surveying. It is possible to find some works where they are applied together in so different scenaries 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. During the constructive process it is necessary to make periodically measurements, and also during the whole life of the building, as a control tool. At the present day some of these measurements are handy-made, with risk of having an industrial accident in some situations. In this work we present a methodology based on a photogrammetric-topographic joining measure system, in order to semi-automating some measurement procedures in building construction. The system consists of a semi-rigid calibrated support putting up a laser distancemeter and a digital camera. 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; calibration of the complete system. The calibration process was made by three different alternatives which are detailed expounded in this contribution.

1. INTRODUCTION

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. 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.

2. CALIBRATION SET UP: DETERMINING UNKNOWN FACTORS

The system consists of a rigid (uncrushable) support to which a laser distancemeter and a digital camera is attached, as shown in the figure below (See Figure 1). The objective is to know: (See Figs. 2 and 3)

1. The relative position between the camera's optical center 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.

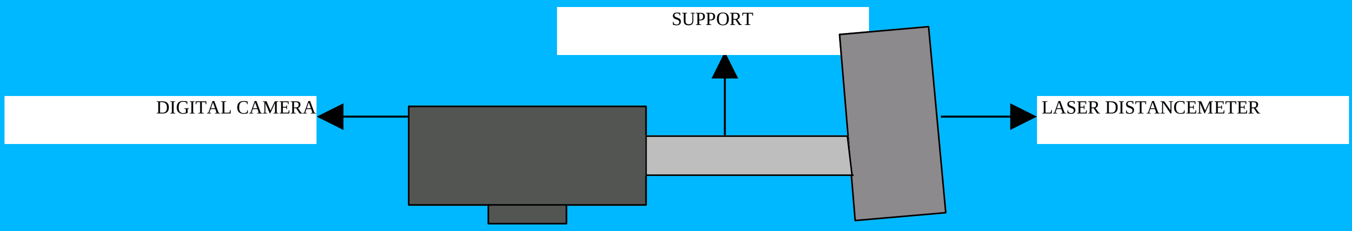

Figure 1. Plan of the complete system formed by the camera and the distancemeter joined by the rigid support.

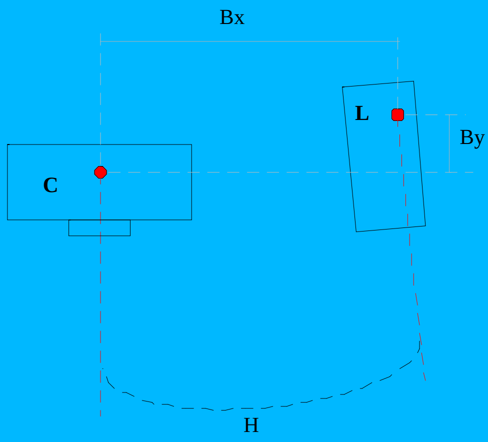

Figure 2. View of the system from above .

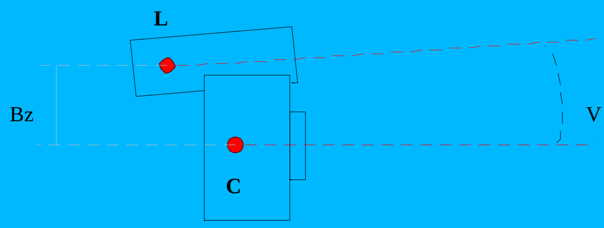

Figure 3. Side view of the system.

It is premised that the camera used is calibrated and that all elements are fixed and immovable.

Considering,

(X_C,Y_C,Z_C) coordinates of the optical centre of the camera
(X_L,Y_L,Z_L) coordinates of the fixed point of origin of the laser distancemeter
(B_X,B_Y,B_Z) components of the base between the optical center of the camera and the fixed point of origin of the laser distancemeter
(V,H) angular components between the optical axis of the camera and the fixed axis of the laser distancemeter

In order to calibrate the system and know (B_X,B_Y,B_Z) and (V,H) different solutions have been suggested, whose variability can be mathematically certified.

The hypotheses analysed as a result are all based on the same procedure of data acquisition, obtaining the different recorded results, in line with the system of coordinates employed and the conditions imposed upon the geometry of the object.

3. METHOD OF DATA ACQUISITION

Regardless of the mathematical option of calibration chosen, the fieldwork method will be the same. The method is such that N photographic shots are taken, from N different positions on a calibrated panel (point net).

The objective is to calculate the coordinates of the point of origin of the laser (center) and the direction of its axis (vector). To make this possible, a method has to be designed that can calculate the position of two different points on a trayectory.

The most precise definition of the center will be obtained if one of the points is as close as it possibly be 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.

To define these two points a photo will be taken as close up as possible to the net and afterwards a second photo taken as far as possible away from the aforementioned panel.

As each photo is taken, a distance measurement will be made, ensuring that the position of the laser mark appears in the photographic image.

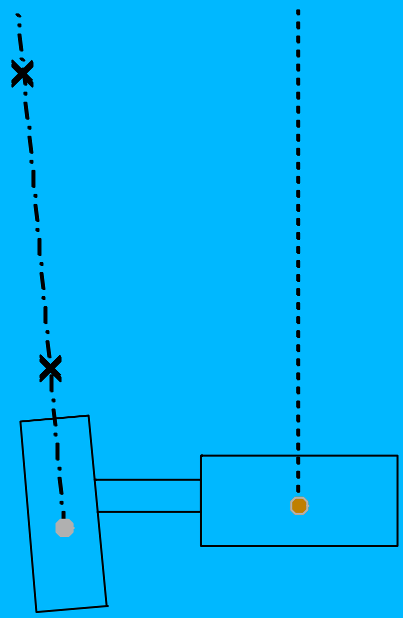

Figure 4. Camera locations in the data acquisition step

Once the photos have been taken and the distance measurements have been recorded in each position, the mathematical calculation system for calibrating can be designed.

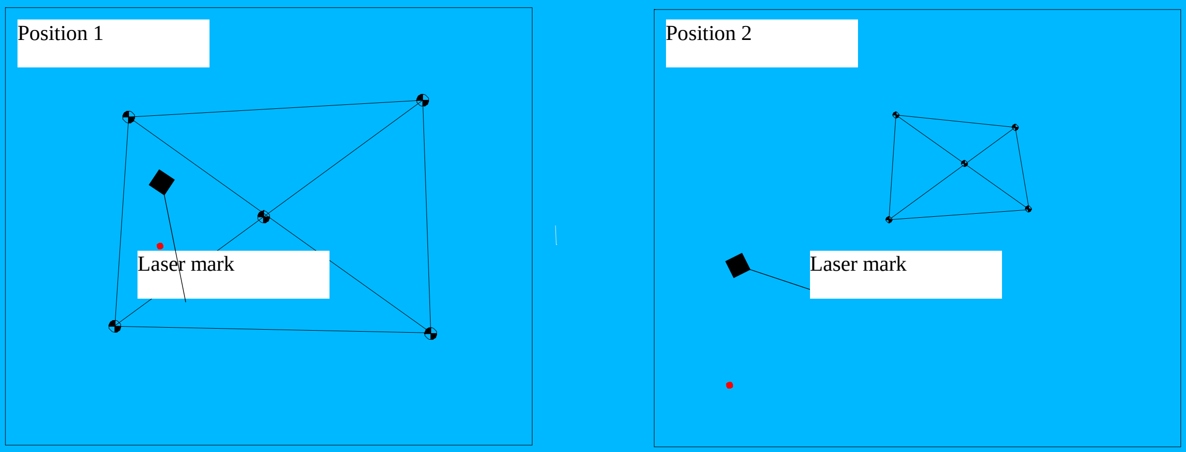

Figure 5. Camera shots taken during the fieldwork process.

4. MATHEMATICAL PROCESSES OF CALIBRATION

As was mentioned before, 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; the fieldwork method will not change. 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.

Therefore the difference between the calibration models will be, as previously mentioned, the point in which the origin of the coordinates system is fixed. The possible variances are:

METHOD 1: Coordinates System is fixed on the camera and the panel is allowed to move.

METHOD 2: Coordinates System is fixed on the panel and the camera is allowed to move.

4.1 Method 1: Taking photographs and laser measurements using a calibrated panel, from two different positions, with the coordinates system fixed on the camera.

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 as in the figure 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 Figure 8.

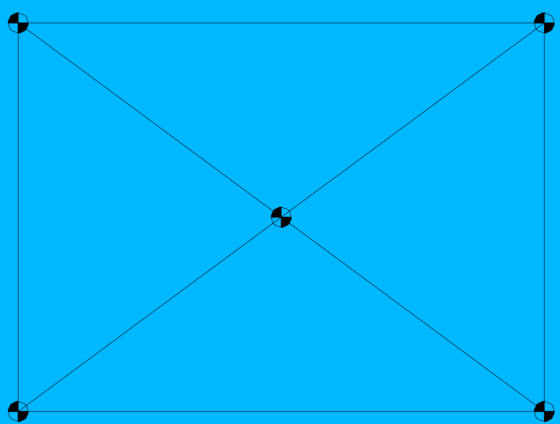

Figure 6. Calibration net

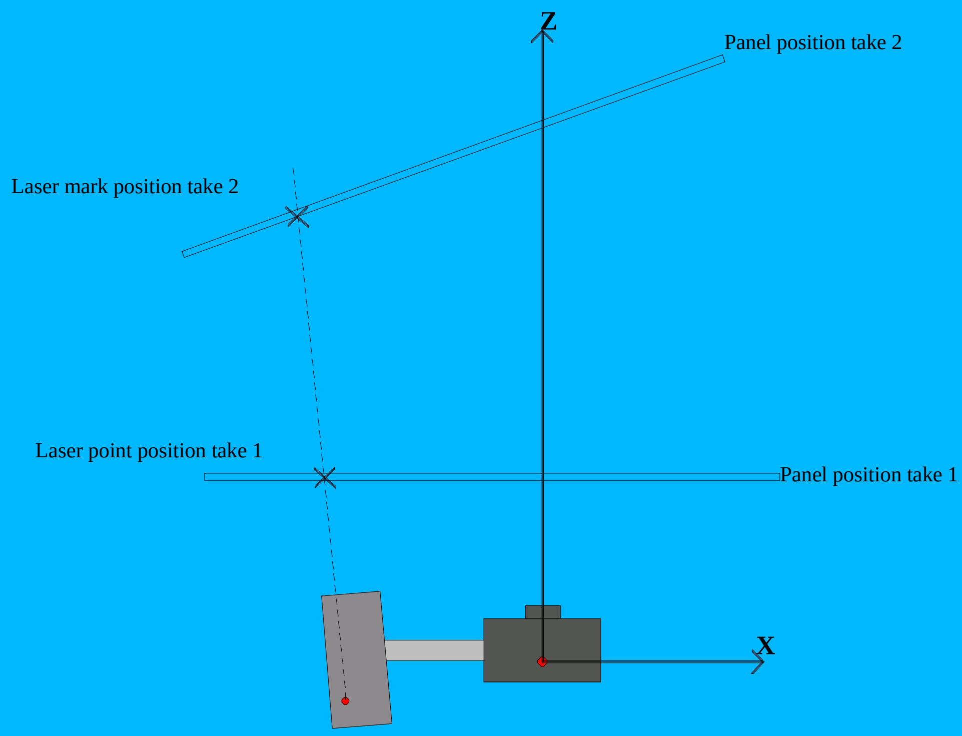

Figure 7. Plan of the calibration process with the system of coordinates on the camera.

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 parallel to the main direction of the shot.

As is widely known, the photogrammetry equation is:

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

Where,

(X_t,Y_t,Z_t) = Coordinates of the corners of the net
(Xo,Yo,Zo) = Coordinates of the camera
(x,y) = Photo-coordinates
f = Main calibrated distance

$$m_{11} = \cos\varphi * \cos\chi$$
$$m_{12} = \cos\omega * sen\chi + sen\omega * sen\varphi * \cos\chi$$
$$m_{13} = sen\omega * sen\chi - \cos\omega * sen\varphi * \cos\chi \quad (2)$$
$$m_{21} = -\cos\varphi * sen\chi$$
$$m_{22} = \cos\omega \cos\chi - sen\omega * sen\varphi * sen\chi$$
$$m_{23} = sen\omega * \cos\chi + \cos\omega * sen\varphi * sen\chi$$
$$m_{31} = sen\varphi$$
$$m_{32} = -sen\omega * \cos\varphi$$
$$m_{33} = \cos\omega * \cos\varphi$$

Given that camera rotations are nil and their coordinates are also nil, aforesaid equations are:

$$Xt = Zt\frac{x}{f}$$
$$Yt = Zt\frac{y}{f} \quad (3)$$

The coordinates of the panel corners are unknown although the geommetry and dimensions are. Using this knowledge, and by labelling the upper left hand corner of the rectangle (Xr,Yr,Zr), there are two unit vectors in the direction of the two retangular sides V1(1, 0, 0) and V2(0 , 1, 0) which rotated in the space with any rotation of type (α,β,γ) and with a translation (Xr,Yr,Zr) positions the vectors, knowing already the longtitude of the two known sides, L_1 and L_2 as we do.

There are therefore 6 unknown values (Xr,Yr,Zr) and (α,β,γ) that make up the coordinates of the 4 corners of the rectangle. If V1r is the result of turning vector V1 and V2r is the result of turning V2:

V1r = [R] * V1
V2r = [R] * V2

Where [R],

$$r_{11} = \cos\beta * \cos\gamma$$
$$r_{12} = \cos\alpha * sen\gamma + sen\alpha * sen\beta * \cos\gamma$$
$$r_{13} = sen\alpha * sen\gamma - \cos\alpha * sen\beta * \cos\gamma$$

$$r_{21} = -\cos\beta * sen\gamma$$
$$r_{22} = \cos\alpha\cos\gamma - sen\alpha * sen\beta * sen\gamma \qquad (5)$$
$$r_{23} = sen\alpha * \cos\gamma + \cos\alpha * sen\beta * sen\gamma$$
$$r_{31} = sen\beta$$
$$r_{32} = -sen\alpha * \cos\beta$$
$$r_{33} = \cos\alpha * \cos\beta$$

The coordinates of the four corners are:

$$(Xr\ Yr\ ,Zr\ )$$
$$(Xr\ Yr\ ,Zr\ ) + V1r * L_1$$
$$(Xr\ Yr\ ,Zr\ ) + V2r * L_2 \qquad (6)$$
$$(Xr\ Yr\ ,Zr\ ) + V1r * L_1 + V2r * L_2$$

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:

$$(Xp,Yp, Zp) = (Xr,Yr,Zr) + a * V1r + b * V2r \qquad (7)$$

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: L1, L2

Unknown values:

- Four spatial positions of the panel corners in each shot, determined by (Xr,Yr,Zr) and (α,β,γ)
- A spatial position of the laser mark in each shot, determined by a and b.

4.2 Method 2 : The coordinates system is established on the wall, with the origin of the coordinates in the top left of te rectangle.

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. 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, as is shown in Figure 9.

In this case the four corners of the rectangle located in the coordinates system in the upper left hand corner are data, as shown:

- 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.

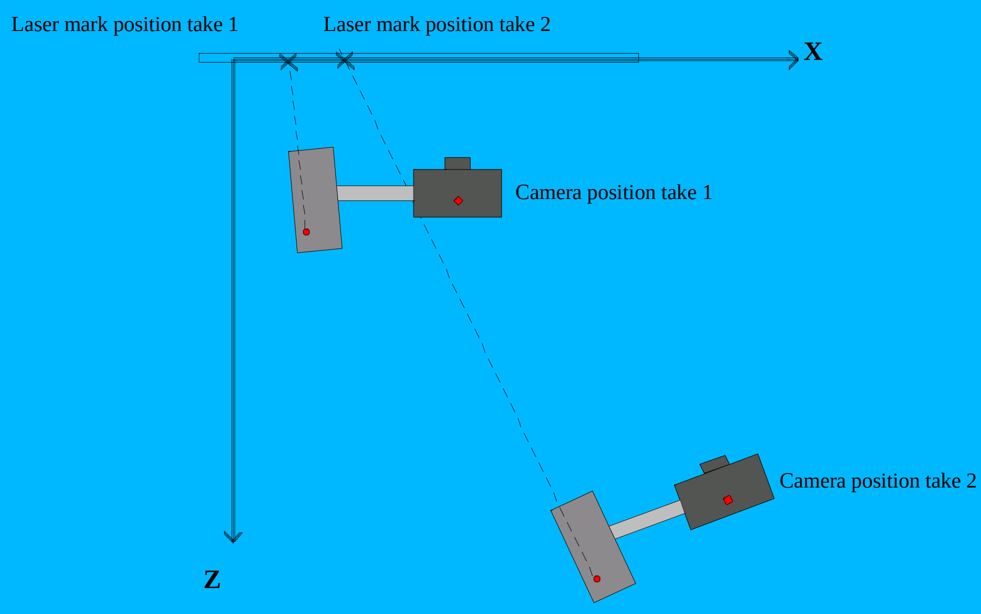

Figure 8. Plan of the calibration process with the coordinates system on the panel.

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: (Xo,Yo,Zo) and (ω,φ,χ).

Turning once again to the photogrammetry equations (1) that give a redundant mathematical system correponding 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 (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 is known is carried out by deducting the distance measured by the vector from any of the laser marks on the panel.

Once the position of the center of the camera and laser are known, the components of the base can be easily obtained (Bx,By,Bz). Together the vector of the laser and the vector defined by the main (calibrated) distance give us the translation 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.

4. CONCLUSSION

Given the feasibility of both mathematic procedures has been demonstrated, several conclusions might be inferred which show the advances of them both.

However, they do differ in an essential factor, involving that the second method becomes the best option.

According to the first exposed 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 of importance. Only the coordinates of at least 4 ground points might be precisely determined, whatever the geometry it has.

This is an important difference, since involves that the second method might be applied in a wide range of cases, while in the first procedure the absence of a rectangular mesh involves that the corresponding equations will not be established, even they are essential for obtaining the final parameters.

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