THE INFLUENCE OF CAMERA CALIBRATION PARAMETERS ON 3D BUILDINGS MODELS CREATION

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Abstract: *In recent years 3D buildings models, have known a great evolution, being used in many scientific domains of activity. For many years, close-range photogrammetry has been dealing with the extraction of high accuracy informations from images. The used techniques, mostly require a very precise calibration of metric and non-metric digital cameras. This article presents the importance of a good determination of the intrinsic parameters in obtaining a high quality and accurate 3D models of buildings. In order to obtain the results, the 3D model of the historical monument "Dosoftey House" from Iaşi- City area was created, using images acquired with the Nikon Coolpix L810 digital camera and the intrinsic parameters determined, using both, a 2D calibration grid and a 3D calibration target. The 3D building models created based on this two sets of parameters, were evaluated based on precise measurements made with a total station.*

Keywords: Non-metric images, building, 3D model, calibration target, accuracy

1. Introduction

Camera calibration is a fundamental process used in photogrammetric measurement, being an integral applied operation within photogrammetric triangulation, especially in high-accuracy close-range measurement [1]. The camera calibration process is necessary to obtain metric information from two-dimensional (2D) images of the three-dimensional (3D) world. In order to obtain precise and reliable 3D metric information from images, there is neccesary to use an accurate camera calibration and also specific orientation procedures. Camera calibration is the basic task, used to determine the optical characteristics of the camera, also called intrinsic parameters. A camera is considered calibrated if there are known the following intrinsic parameters: the focal length, the image coordinates of the principal point, the radial and tangential distortion coefficients.

Camera calibration continues to be an area of active research within the CV community, with a perhaps unfortunate characteristic of much of the work being that it pays too little heed to previous findings from photogrammetry [2]. Over the years, in the photogrammetry and CV literature, have been reported various algorithms for camera calibration [3]. These algorithms are generally based on perspective or projective camera models and they are developed by several authors, such as: Tsai (Tsai, 1987), Heikkilä [4], [5], Bakstein & Halir (Bakstein & Halir, 2000) and Zhang (Zhang, 2000).

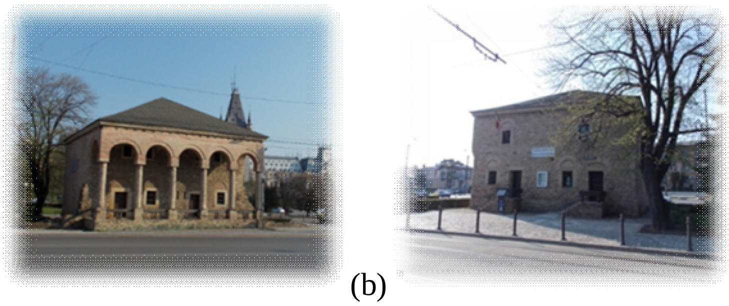
In this paper is presented the Heikkilä and Silven's calibration method to determine the parameters of the non-metric digital camera Nikon L810. This technique first extracts initial estimates of the camera parameters using a closed-form solution (DLT) and then a nonlinear least-squares estimation is applied to define the interior orientation and compute the distortion parameters. The model uses two coefficients for both radial and decentering distortion, and the method works with single or multiple images and with 2D or 3D calibration grids [6].

The principal purpose of this article is to find out the intrinsic parameters of a non-digital camera using two different calibration targets: first using a 3D calibration target and secondly, a 2D calibration grid, in order to determine how much they can affect the accuracy of the final 3D model of a building, created based on digital images.

2. Presentation of the Study Area, Materials and Equipment

2.1. Presentation of the Study Area

The “Dosoftei House” also known as “The House with Arcades”, located in Iasi city (Romania), Anastasie Panu Avenue no.54, was the Metropolitan of Moldavia between 1670 and 1686 and nowadays, it is the Museum of Old Moldavian Literature from 1970. The historical monument is built from stone, having a special architecture with a regular shape that is cubic (Fig. 1).



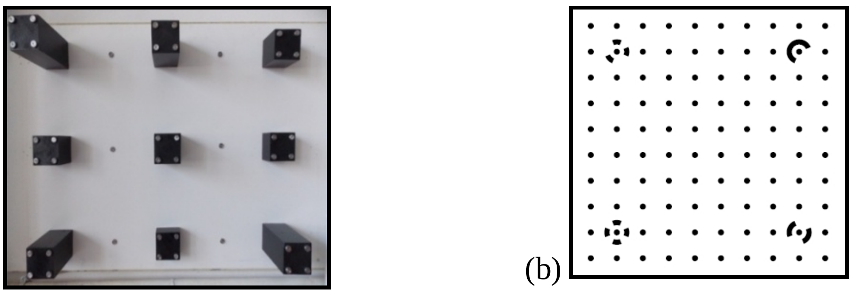
(a) (b)

Fig. 1. The study building - “Dosoftei House” Museum (a) perspective view of the main facade and (b) perspective view of the main side facade

2.2. Materials and Equipment

The images were taken with a Nikon Coolpix L810 digital photo bridge camera (16.1 Mega pixel), equipped with a 6,26 mm by 4,69 mm image sensor. In this paper, it was used the smallest focal length, the digital images with the greatest resolution of 4608 x 3456 pixels and a 1,359 μm pixel size.

The camera calibration was made in two different manners. Firstly, it was used as a 3D calibration object, a target consisting in a number of 42 points, 36 placed in the corners of 9 wood cubes with different heights and 6 placed of them at the middle of the distance between the cubes, on a board. This target was attached to a room wall. Secondly, it was used a grid consisting in a number of 100 points as a 2D calibration grid (Fig. 2).



(a) (b)

Fig. 2. The calibration grids – (a) 3D calibration grid and (b) 2D calibration grid

The 42 control points have 18 mm in diameter and consist of metal parts manufactured by means of a lathe. In order to place the 3D calibration grid target in the world coordinate system, a coordinate measuring machine (CMM), produced by Aberlink was used, with an uncertainty within the working space of 2 μm.

2.3. Data processing

The image coordinates of the control points were determined using “Lisa” software. This programme is a digital photogrammetric soft and its main functions are: import and orientation of the images, image co-ordinate measurement for aerial triangulation (ATM; manual or automatic), aerial triangulation, measurement of terrain co-ordinates (mono- or stereoscopic, with / without connected DTM), automatic derivation of surface models, creation of ortho images and mosaics.

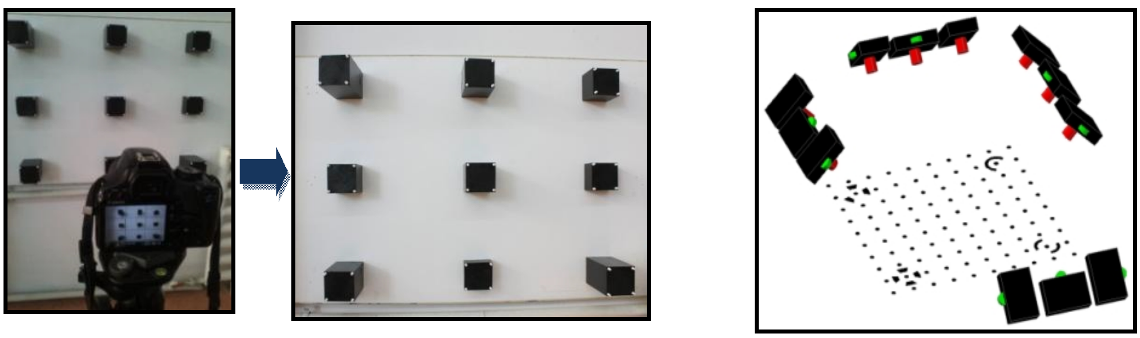
In order to obtain the 3D model of the building, the images were processed with the “PhotoModeler Scanner 6” software developed by Eos Systems Inc. Company from Vancouver, Canada. This software creates 3D models from images taken with an ordinary camera and extracts 3D measurements, representing a very cost-effective way of doing accurate 3D scanning, measurement and surveying. This software was also used tor realize the calibration process, using the 2D calibration grid.

For the calibration process using the 3D calibration target, the Matlab programme was used. This is a high performance language for technical computing, which integrates numerical computation, visualization and programming. It is used to analyze data, to develop algorithms, and create models and applications.

3. Results and discussion

3.1. Calibration parameters calculation using 2D and 3D calibration targets

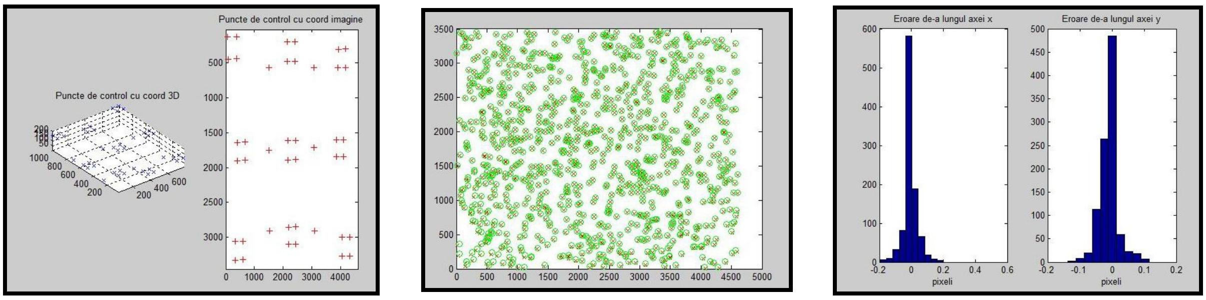
For the two calibration methods using 3D and 2D calibration grids, in a first phase, image observations of the targets were taken. So, for the first method, it was taken a single image of the 3D target, in a normal position, at the distance of 1 meter, with the smallest focal length and for the second method, using the 2D target, 12 images from 12 different camera positions were taken (Fig. 3).



(a) (b)

Fig. 3. Image observations using the Nikon Coolpix L810 digital camera (a) of the 3D calibration target and (b) of the 2D calibration target [7]

Firstly, the calibration process using the 3D calibration target was carried out, using the camera calibration toolbox for Matlab (version 3.0) implementing the Heikkila and Silven’s method (Fig. 4).



(a) (b) (c)

Fig.4. Heikkila and Silven’s calibration method - (a) The control point positions in the world coordinate system relative to image system, (b) differences between distorted and original coordinates for 1000 randomly distributed points, (c) the errors caused by the back-projection model in horizontal direction and vertical direction

This Matlab program computes the intrinsic parameters of the Nikon Coolpix digital camera, as they are presented in Table 1.

Table 1. The Nikon Coolpix L810 digital camera intrinsic parameters obtained with the 3D calibration target, for the minimum focal length **f=4 mm**

Focal length	f [mm]	u_0 [pixeli]	v_0 [pixeli]	k_1 [mm]	k_2 [mm]	p_1 [mm]	p_2 [mm]
f=4 mm	4.0958	2345.857	1751.143	$7.2721 \cdot 10^{-4}$	$-3.3710 \cdot 10^{-5}$	$-1.2215 \cdot 10^{-3}$	$-2.5316 \cdot 10^{-4}$

Secondly, the calibration process using the 2D calibration target was made. The 2D calibration grig was placed on the flat surface of a board and the camera was mounted on a tripod. The twelve 2D calibration target images were processed using "PhotoModeler Scanner" software and the resulted intrinsic parameters, are shown in Table 2.

Table 2**.** The Nikon Coolpix L810 digital camera intrinsic parameters obtained with the 2D calibration target, for the minimum focal length **f=4 mm**

Focal length	f [mm]	u_0 [pixeli]	v_0 [pixeli]	k_1 [mm]	k_2 [mm]	p_1 [mm]	p_2 [mm]
f=4 mm	4,1353	2361,077	1752,545	$1,3450 \cdot 10^{-4}$	$-5,5560 \cdot 10^{-5}$	$-1,0260 \cdot 10^{-3}$	$9,9590 \cdot 10^{-4}$

3.2. Comparative analysis of calibration parameters

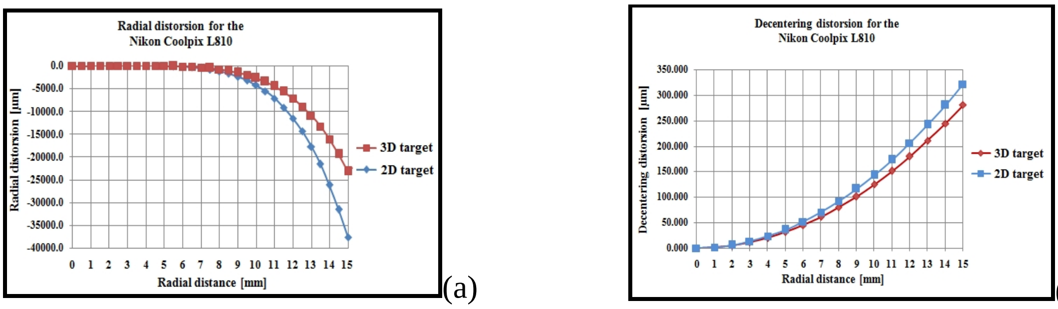
After the calibration process of the Nikon Coolpix L810 digital camera, using the 3D and 2D targets, a comparative analysis of the two different seths of the intrinsic parameters was realized, the differences being presented in Table 3.

Table 3 - The results of the calibration process of the Nikon Coolpix L810 digital camera

Parameter	**Calibration target 3D/2D [mm]**	**Differences [mm]**	**Differences [%]**
Focal length	4,0958 / 4,1353	-0,0395	-0,964403
Principal point (x_p)	3,1873 / 3,2080	-0,0207	-0,648774
Principal point (y_p)	2,3793 / 2,3812	-0,0019	-0,080071

The first comparison was made on the two focal lengths and the second on the image coordinates of the principal point, noticing that the differences between the two sets, don’t get by the value of -1%.

The distorsions were computed for the border of the image, at 15 mm in relation to the image center. For the radial distorsion the smallest difference was of 0,017 mm and the greatest of 14,5 mm and for the descentering distorsion the smallest difference was of -0,041 mm and the greatest of -0,01 mm. The two profiles of the radial and descentering distorsion, based on the computed intrinsic parameters, are represented in Fig.5.



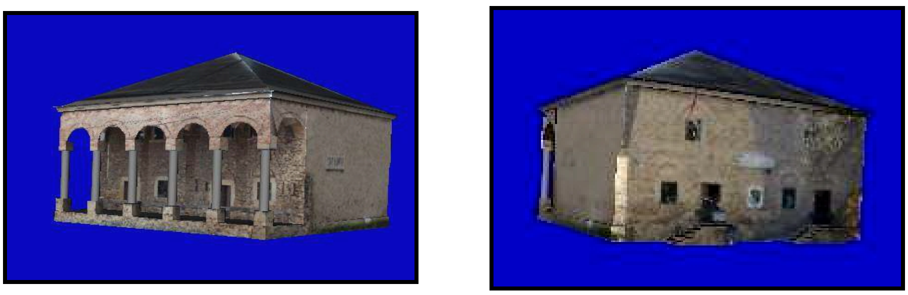
(a) (b)

Fig. 5. (a) Radial and (b) decentering distortion profiles for the Nikon Coolpix L810 digital camera, computed using the 3D and 2D calibration parameters

3.3. The 3D model creation

For the 3D model creation of the *“Dosoftei House”* Museum, the *“PhotoModeler Scanner”* software was used. Firstly, a number of ten images were taken around the building with the same camera, from ten different positions, by different angles. In order to process this images, the method of manually match common features between photos was used.

After the correlation process was finished, the 3D model of the building was created, firstly using the intrinsic parameters computed using the 3D calibration target. In order to obtain the real position of the building, this 3D model was scaled and rotated, using the 3D known coordinates of three characteristic points, located on different facades, with sensible distances between them. The coordinates were determined by reflector less measurements made with a total station. In order to get a real appearance of the building, the 3D model model was textured, using the software’s high- quality option.



(a) (b)

Fig. 6. The *“Dosoftei House”* 3D model, created in the “PhotoModeler Scanner” software (a) perspective view of the main facade, (b) perspective view of the main side facade

In order to obtain the 3D model of the “Casa Dosoftei” museum, using the intrinsic parameters obtained from the 2D target calibration process, the same project was used. The steps followed were the same as presented before, the only difference being the replacement of the calibration parameters.

3.4. Comparative study on 3D models

In order to find the most accurate calibration parameters, was evaluated the accuracy of the two digital models of the same building, by pointing out the differences between the values of two sets of coordinates of 20 characteristic points of the building (window edges, door, etc.) (Table 4). As a reference base, the real coordinates rigorously obtained with the total station Leica TCR 407 were used. The plane rectangular coordinates were determined in the National Projection System, namely "Stereographical on unique secant plan-1970" and the normal altitudes in the „Black Sea 1975" reference system for heights, through the GNNS technology using the South S82-V GNSS Rover.

Table 4. The differences between the two sets of coordinates

Point no.	Differences - PhotoModeler (2D target) – Total Station ΔX (m)	ΔY (m)	ΔZ (m)	Differences - PhotoModeler (3D target) – Total Station ΔX (m)	ΔY (m)	ΔZ (m)	RMSE (m) PhotoModeler - 2D target	RMSE (m) PhotoModeler - 3D target
1	-0.038	0.196	-0.170	0.035	0.020	0.020	0.263	0.045
2	0.166	-0.080	0.000	0.166	-0.060	0.000	0.184	0.177
3	-0.157	0.258	-0.018	-0.131	0.263	0.040	0.303	0.296
4	0.181	0.253	0.039	-0.061	0.091	-0.007	0.314	0.110
5	0.376	0.140	-0.016	-0.065	-0.033	-0.033	0.402	0.080
6	0.475	0.289	-0.097	0.049	0.025	0.101	0.320	0.115
7	0.411	0.216	-0.176	-0.034	-0.005	-0.025	0.496	0.042
8	0.178	0.308	-0.746	0.011	-0.029	0.083	0.290	0.089
9	0.355	0.146	-0.047	-0.070	-0.045	0.020	0.387	0.085
10	-0.194	0.078	0.049	0.070	0.069	-0.257	0.214	0.275
11	-0.346	-0.321	-0.245	0.107	-0.026	-0.103	**0.440**	0.151
12	-0.366	-0.015	-0.073	0.071	0.032	-0.261	0.373	0.272
13	-0.380	0.005	-0.181	-0.099	-0.063	-0.115	0.421	0.164
14	-0.365	-0.156	-0.025	0.048	0.111	-0.290	0.397	0.314
15	-0.146	0.314	-0.029	-0.121	0.296	0.028	0.347	0.322
16	-0.087	0.277	-0.030	-0.011	0.011	0.029	0.292	0.033
17	-0.103	0.263	-0.017	-0.043	0.244	0.009	0.283	0.248
18	-0.188	0.377	-0.152	-0.193	0.250	-0.150	0.390	**0.250**
19	-0.296	0.367	-0.190	-0.291	0.010	-0.294	0.360	0.320
20	0.386	0.307	-0.234	-0.031	0.069	-0.038	0.380	0.084
							0.343	**0.179**

The results show the maximum differences of 47 cm on the X coordinate, 37 cm on the Y one and 5 cm on Z axis for the model created using the 2D calibration parameters and 16 cm on X coordinate, 29 cm on Y and 10 cm on Z axis, for the second model.

The Root Mean Square Error was computed, using the following formula [8]:

$$RMS_{error} = \sqrt{\left(X_r - X_i\right)^2 + \left(Y_r - Y_i\right)^2 + \left(Z_r - Z_i\right)^2} \quad (1)$$

where: X_r, Y_r, Z_r – the coordinates obtained with the total station TCR 407 Ultra,

Xi, Yi, Zi – the coordinates obtained by digital 3D models interrogation.

The greatest total error obtained for the model created using the 2D calibration parameters was of **44 cm** and for the model obtained using the 3D parameters, was of **25 cm**.

After the results analysis, the **Root Mean Square Error** for the 3D model created using the intrinsic parameters calculated using the 2D calibration target is of **34 cm**, in comparison with the other one, created using the 3D calibration target, which is of **17 cm**.

The overall residual of the project using the parameters based on the 2D calibration target, was of 1.772 pixels. It was also realised the errors distribution histogram of the detail points coordinates, measured in image coordinate system (Fig. 7) and the error repartition of the building characteristic points image coordinates (Fig. 8).

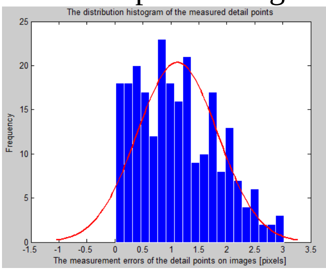


Fig. 7. The errors distribution histogram of the measured detail points image coordinates

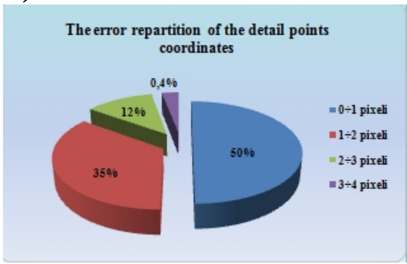


Fig. 8. The error repartition of the building detail points image coordinates

The angles between the projection rays of the detail points range between 8^{o}68'75" and 89^{o}55'51", with an average of 52^{o}16'97" as they are shown in intervals of 20^o in Fig. 9.

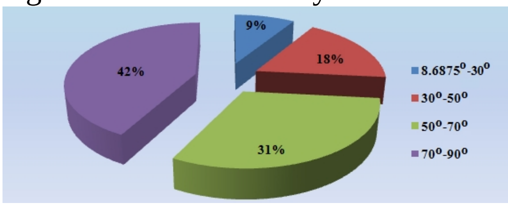


Fig. 9. The repartition of the angles between the projection rays, used in points coordinates computation, using the calibration parameters obtained with the 2D calibration target

For the project using the calibration parameters computed with the 3D calibration target, the overall residual was of 1.401 pixels, less than the project error based on the parameters obtained with the 2D calibration target. It was also realised the errors distribution histogram of the detail points image coordinates (Fig. 10) and their repartition (Fig. 11).

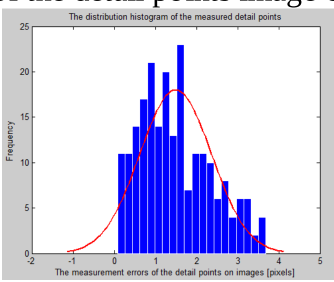


Fig. 10. The errors distribution histogram of the measured detail points image coordinates

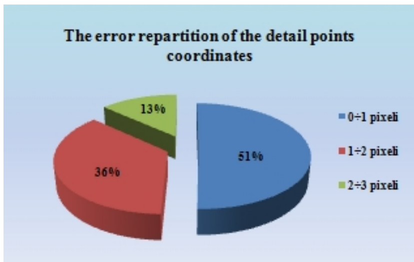


Fig. 11. The error repartition of the building detail points image coordinates

In the case of the distribution of medium angles between the projection rays, corresponding to building characteristic points, a chart based on the angles values grouped in intervals of 20^o is shown in Fig. 12. The angles range between 12^{o}06'71" and 89^{o}94'93", with an average of 52^{o}24'19".

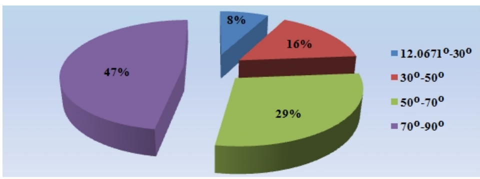


Fig. 12. The repartition of the angles between the projection rays used in points coordinates computation, using the calibration parameters obtained with the 3D calibration target

4. Conclusions

Nowadays, the evolution of technology lead to a great evolution of 3D building modelling creation, in a very short time. The problem of realistic 3D buildings model creation is met in domains as city planning, architecture and preservation, the requirements of the users being minors.

The 3D reconstruction, modelling, documentation, monitoring and visualization of buildings can be realized using photogrammetric methods, with a relative good accuracy and at a smaller price, in comparison with other technologies. The biggest advantage of this technology is the economy in the used procedures. The surveys are easier than those made with a total station, because, in the last case, a big number of measured points is necessary and the operator's effort is more difficult. The 3D model is created in a very short time and it can be exported to other softwares or applications.

After comparing the spatial coordinates (X, Y, H) of 20 characteristic points of the building 3D model created using the "PhotoModeler" software, with the ones measured with the total station, the cumulative root mean square error was of **34.3 cm** for the 2D calibration grid and of **17.9 cm** for the 3D calibration target. The difference is semnificative and it can be concluded that the precision was improved with approximately 50%.

The accuracy of the 3D models created based on digital non-metric images depends on the type of the camera used and its technical characteristics, the geometry of the point station network for taking the images, the accuracy of the image identification process of the object space points and their number (as indicated at least 10 referenced points in every image). It is very important not to mark on the image points that can not be clearly identified due to blur or obstacles, fewer points providing better accuracy than points that were wrong marked.

Photogrammetry offers the possibility of obtaining the 3D coordinates of an object from 2D digital images, in a very fast way and with lower prices. So, this technology is used for object modeling with very good results, in a realistic way.

5. References

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