DIGITAL IMAGES AND TOTAL STATION MEASUREMENTS FUSION FOR 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. In this paper is presented a method for 3D building model creation, using digital images and total station measurements. For this case study, the historical monument "Vovidenia church" from Iaşi City was chosen. Due to the fact that the north part of the church is occluded, also by trees and the property limit, digital images couldn't be taken in ideal conditions. So, this part of the church, was modeled in 3D using total station measurements, made for building characteristic points: corners of windows, doors, etc. The south part was modelled based on digital images, acquired with the Nikon Coolpix L810 digital camera, calibrated with a 3D calibration target. Finally, the two results were fused into AutoCAD software and the final 3D model was created. The 3D building model, was evaluated by comparing the coordinates of 20 building characteristic points, as resulted from the total station measurements and by digital images processing respectively.*

Keywords: *digital images, total station, building, 3D model, accuracy*

1. Introduction

Nowadays, there is a growing interes in the construction of 3D models, especially of 3D models of urban and built environment for which a host of digital mapping and rendering techniques are being developed [1].

The importance of up-to-date and accurate geospatial information has been emphasized with the increasing demand for Geographic Information Systems (GIS). Digital Building Model (DBM) is one of the important components among the geospatial information especially in urban areas. They are required as an input in many applications, such as city modelling, natural disaster planning and aftermath evaluation, search and rescue environmental studies, tourism, cartography, mobile navigation and telecommunication network planning. With the development of sensor technology and the increase of user requirements, many different approaches for efficient building model generation have been proposed, such as: Rottensteiner, Habib, Huang and Sester. They can be categorised according to the data source used, the data processing strategy and the amount of human interaction [2].

The 3D models of buildings are useful for many applications such as urban planning and environmental simulation, cartography, tourism and mobile navigation. Automatically generating building models, in the form of 3D CAD representation, is the major part of city modeling and a challenge for many researchers [3].

The geometric resolution represents an important feature data, which determine the level of detail for the creation of the final 3D digital buildings models. Depending on the needs and the geometric resolution of the data used, the same building can be represented at different levels of detail. There are 5 levels of detail (LOD) for reconstruction and 3D visualization of buildings: the coarsest level LOD0 is essentially a two and a half dimensional digital terrain model (DTM); LOD1 is the well-known blocks model, without any roof structures; LOD2 has distinctive roof structures and larger building installations like balconies and stairs; LOD3 denotes architectural models with detailed wall and roof structures, doors, windows and bays; LOD4 completes a LOD3 model by adding interior structures like rooms, stairs, and furniture [4].

In order to increase the accuracy of the 3D models, there are proposed three additional levels of detail: LOD2A - visualization of general buildings façades; LOD2B - visualization of bicolour buildings with roofs structures; LOD2C - visualization of bicolour buildings with roofs super-structures [5].

In order to create digital 3D buildings models, information data source needs to be collected. There are different types of used data, like: optical data (monoscopy, stereoscopy, multiscopy), Terrestrial Laser Scanner data (TLS), Airborne Laser Scanner data (ALS) and terrestrial surveying data.

In this paper is presented a method for 3D building model creation, using digital images and total station measurements. In order to obtain the 3D digital model of the historical monument “Vovidenia” church from Iaşi City, a fusion of the two different data information was performed. The north part of the church couldn’t be photographed in ideal conditions, because of the property limit and areas occluded by trees. That’s why, images were substituted with classical total station measurements.

The principal purpose of this article is to determine what degree of confidence and in what conditions, the two different information data fusion can be used to reconstruct a building in 3D.

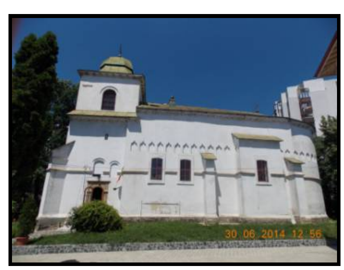
2. Presentation of the Study Area, Materials and Equipment

2.1. Presentation of the Study Area

The “Vovidenia” church located in Iaşi City (Romania), Vovideniei Street no. 11, is included in the historical and architectural patrimony of the town. It was build in the XVII century, having a stone masonry, with an architectural regular shape of cross.

The orthodox church has its dedication day “The Entry of the Most Holy Mother of God into the Temple”, celebrated on 21 november every year.

(a)



(b)

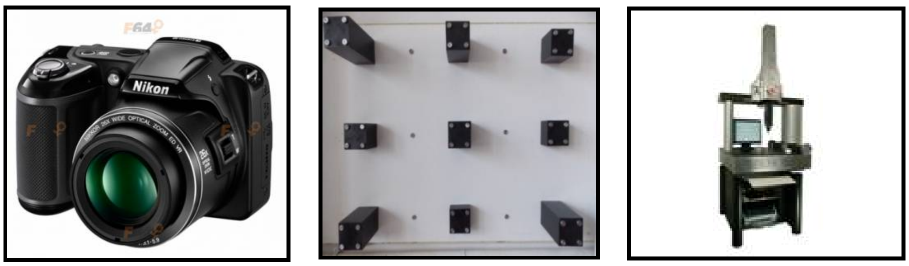
Fig. 1. The study building - “Vovidenia church” - perspective view of the south façade
(a) south-west view and (b) south view

2.2. Materials and Equipment

The images were acquired 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 (Fig. 2a). In this paper, the digital images with the greatest resolution of 4608 x 3456 pixels and a 1,359 μm in pixel size, taken with the minimum focal length, were used,.

The camera calibration was made with a 3D calibration grid, a target consisting in a number of 42 points, 36 placed in the corners of 9 wood cubes and 6 placed at the middle of the distance between them, with different heights. These 42 control points have 18 mm in diameter and consist of metal parts manufactured by means of a lathe (Fig. 2b). This grid was attached to a room wall.

In order to place the 3D calibration grid target in the world coordinate system a coordinate measuring machine (CMM) was used. This device is produced by Aberlink , with an uncertainty within the working space of 2 μm (Fig. 2c).



(a) (b) (c)

Fig. 2. (a) Nikon Coolpix L810 digital photo camera, (b) 3D calibration grid, (c) coordinate measuring machine (CMM)

On the other hand, the north part of the church, was modeled in 3D using traditional surveying. For this purpose, the Leica TCR 407 total station and a GNSS South S82V receiver were used.

2.3. Data processing

In order to determine the coordinates of 3D calibration grid control points, Lisa software was used. This is a digital photogrammetric program created by Dr.-Ing. Wilfried Linder, Bad Pyrmont – Hagen from Germany 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.

The calibration process was made using a Matlab programme. This is a high performance language for technical computing, developed by MathWorks, which allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python.

The south part of the 3D digital model was created with the PhotoModeler Scanner 6 software, developed by Eos Systems Inc. Company from Vancouver, Canada. The software creates accurate 3D models (consisting of Points, Lines, Curves, Edges, Cylinders, Surfaces, and Shapes), and accurate 3D measurements from photographs taken with most standard cameras (either digital or film). The 3D models can be created and exported with photographic textures extracted from the original photographs.

The north part of the church was modeled in 3D using total station measurements, made for the building characteristic points, which were inserted into AutoCAD software.

The final 3D digital model of the "Vovidenia" church from Iasi was created through the fusion of the two results into AutoCAD 3D software, which is a commercial software application for 2D and 3D computer-aided design (CAD) and drafting, developed by the American multinational software corporation Autodesk, Inc. AutoCAD, used across a wide range of industries, like: architecture, project management, engineering, design.

3. Results and discussion

3.1. The calibration process

Camera calibration is a fundamental process in photogrammetric measurement, used to determine the intrinsic parameters of the camera, like: the focal length, the image coordinates of the principal point, the radial and tangential distortion coefficients.

In this paper, the calibration process uses the Heikkilä and Silven's 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 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, with a 2D or 3D targets [6].

For the calibration process using the 3D calibration target [7], the first step was to take a single photo of the 3D target, at the distance of 1 meter, in a normal position of the camera, using the minimum focal length (Fig. 3).

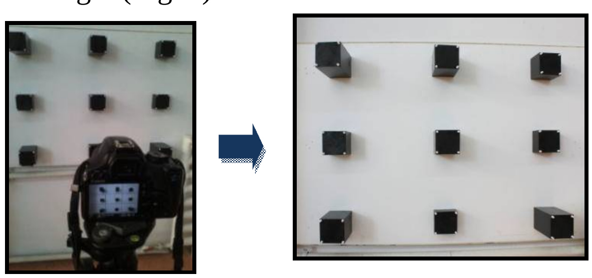
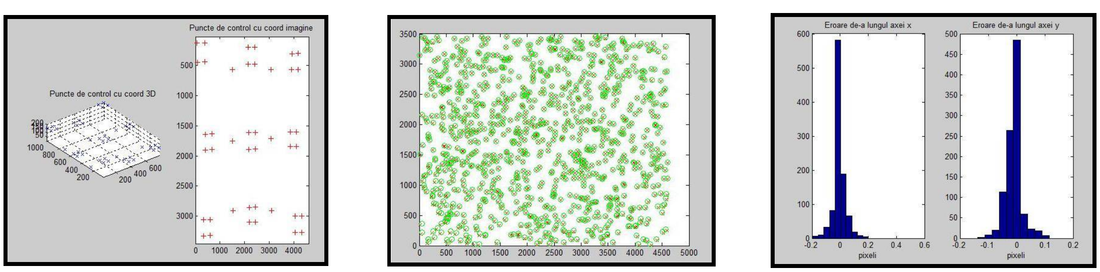


Fig. 3. Image observation of the 3D target, using the Nikon Coolpix L810 digital camera

In the calibration process a Matlab program was used, which includes more functions and generates several figures and histograms, as they are shown in Fig.4. It is based on the algorithm developed by Heikkila and Silven which includes a new adjustement procedure for the circular control points and a recursive method for distorsion [8].



(a) (b) (c)

Fig.4. Camera calibration algorithm - (a) The control point positions in the world coordinate system relative to image system, (b) Differences between distorted and real coordinates for 1000 randomly distributed points, (c) Vertical and horizontal accuracy

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

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	$7{,}2721 \cdot 10^{-4}$	$-3{,}3710 \cdot 10^{-5}$	$-1{,}2215 \cdot 10^{-3}$	$-2{,}5316 \cdot 10^{-4}$

3.2. The 3D model generation of the historical monument "Vovidenia church"

The first step in the generation of the 3D building model, is the digital non-metric images acquisition of the historical monument "Vovidenia church" building facades. The photos are taken around the building, with a 25%-60% overlap and with an angle of at least 20^o between them. All images were taken with the minimum focal length of the Nikon Coolpix L810 camera lens (4 mm), mounting the camera on a tripod at each station point, and buble leveling the digital camera.

The photos acquired using the Nikon Coolpix L810 digital camera, were imported into the "*PhotoModeler Scanner*" software. For this case study the "*Marking & Referencing*" method was used, every detail point or line of the building being manually marked and referenced. Following the bundle adjustment process, the "*PhotoModeler Scanner*" software, calculated the three-dimensional coordinates of 125 characteristic points of the *"Vovidenia church"* building, in a local coordinate system, based on a number of seven photos.

In order to convert the coordinates of the building characteristic points from the local system in the world system, the coordinates of three control points were introduced. In this way, the 3D digital model of the historical monument *"Vovidenia church"* building is scaled, rotated and brought to its real spatial position.

The 3D building model (Fig. 5) was created based on the characteristic building points and lines, using the "*PhotoModeler Scanner*" software specific functions, like: *"Mark Points Mode"*,*"Mark Lines Mode"*, *"Mark Curves Mode"*, *"Path Mode"*, *"Loft Mode"*.

(a) (b) (c)

Fig.5. The „*Vovidenia church"* building model, created using the *"PhotoModeler Scanner"* software, based on the digital non-metric images - perspective view of the south façade (a) in shaded mode, (b) quality textures and (c) south-west view

Due to the fact that the north part of the church is occluded, also by trees and by the property limit, digital images couldn't be taken in ideal conditions. So, this part of the church, was modeled in 3D using total station measurements, made for building characteristic points: building, windows and doors corners.

All the measured points were imported into *"AutoCAD"* software and the 3D building model (Fig. 6) was created using the specific 3D functions of the program.

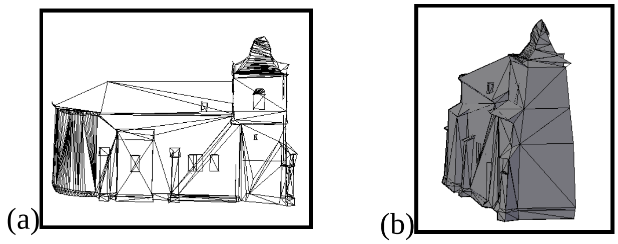


Fig.6. The „Vovidenia church" building model, created into "AutoCAD" software, perspective view of the north façade (a) in Wireframe mode, (b) in realistic mode

Finally, the two results were fused into AutoCAD software and the 3D digital model of the historical monument "Vovidenia church" from Iaşi City was created (Fig.7).

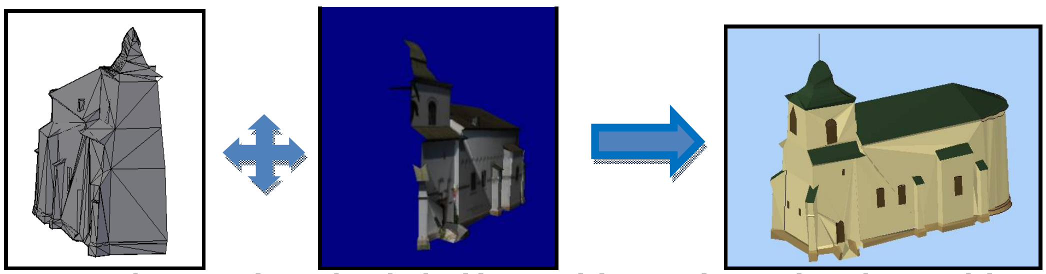


Fig. 7. The „ Vovidenia church" building model, created using the "PhotoModeler Scanner" software, based on the digital non-metric images and into AutoCAD software, based on total station measurements, made for building characteristic points

3.3. Quality assessment of the 3D building model

The 3D building model, was evaluated by comparing the coordinates of 20 building characteristic points, like: building corners, windows and doors corners, as resulted from the total station measurements and by digital images processing, as shown in Table 2.

Table 2 – The differences between the rectangular Stereographic 1970 coordinates of points

No. Point	Total Station TCR 407			PhotoModeler - 3D target			Differences			Total error
	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)	ΔX(m)	ΔY(m)	ΔZ(m)	
201	632760.598	696257.157	76.660	632760.656	696257.879	76.685	0.058	0.422	0.025	0.225
202	632761.063	696257.095	76.660	632761.134	696257.154	76.685	0.071	0.059	0.025	0.096
203	632761.075	696257.072	77.340	632761.124	696257.178	77.365	0.049	0.106	0.025	0.119
204	632760.617	696257.135	77.320	632760.659	696257.321	77.348	0.042	0.186	0.028	0.193
205	632762.586	696256.898	76.710	632762.642	696256.935	76.738	0.056	0.037	0.028	0.073
206	632763.056	696256.820	76.710	632763.100	696256.872	76.738	0.044	0.052	0.028	0.074
207	632763.095	696256.830	77.380	632763.138	696256.855	77.412	0.043	0.025	0.032	0.059
208	632762.598	696256.888	77.400	632762.630	696256.929	77.452	0.032	0.041	0.052	0.074
209	632761.309	696257.007	84.330	632761.530	696257.453	84.376	0.221	0.446	0.046	0.470
210	632762.810	696256.826	84.350	632762.880	696256.873	84.373	0.070	0.047	0.023	0.087
211	632762.920	696256.632	85.950	632762.879	696256.493	85.982	-0.041	-0.139	0.032	0.148
212	632762.824	696256.826	85.950	632762.898	696256.855	85.985	0.074	0.029	0.035	0.087
213	632761.276	696257.001	85.960	632761.305	696257.092	85.996	0.029	0.091	0.036	0.102
214	632759.206	696275.351	77.510	632759.271	696275.309	77.552	0.065	-0.042	0.042	0.088
215	632759.032	696274.385	77.500	632759.079	696274.532	77.552	0.047	0.147	0.052	0.163
216	632759.025	696274.398	79.360	632759.095	696274.475	79.382	0.070	0.077	0.022	0.106
217	632759.198	696275.421	79.350	632759.235	696275.472	79.378	0.037	0.051	0.028	0.069
218	632768.161	696264.728	79.330	632768.195	696264.780	79.372	0.034	0.052	0.042	0.075
219	632768.162	696264.723	77.490	632768.248	696264.789	77.473	0.086	0.066	-0.017	0.110
220	632768.359	696265.728	77.500	632768.393	696265.795	77.562	0.034	0.067	0.062	0.097
							0.056	**0.106**	**0.032**	**0.152**

In Table 2 are shown the rectangular coordinates (X, Y, Z) of 20 detail points of the building, the real coordinates, computed and rigorously determined after the measurements made with the total station Leica TCR 407, and those obtained by interogation of the 3D model created into "PhotoModeler Scanner" software. The differences between them are calculated, using as a reference base the coordinates obtained based on total station measurements.

The results show differences of 22 cm on the X coordinate, 42 cm on the Y one, and respectively, 6 cm on Z axis.

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

$$RSMS = \sqrt{(X_r - X_i)^2 + (Y_r - Y_i)^2 + (Z_r - Z_i)^2}$$

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

Xi, Yi, Zi – the coordinates obtained with digital fotogrammetric technology

It can be noticed that the greatest total error obtained is of 47 cm and finally, after the results analysis, the *Cumulative Root Mean Square Error* the Root Mean Square Error of the model is of 15 cm.

The overall residual of the project was of 1.756 pixels, less then the value of 5 pixels, recommended by the *"FotoModeler Scanner"* software.

The errors distribution histogram of the measured detail points image coordinates was realized (Fig. 8) and also the error repartition of the building detail points image coordinates (Fig. 9).

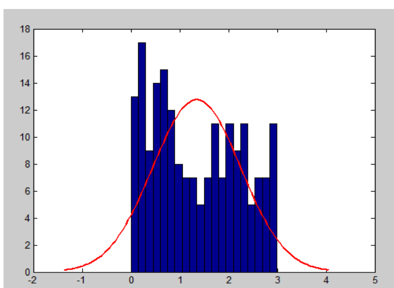


Fig. 8. The errors distribution histogram of the measured detail points in image coordinate system

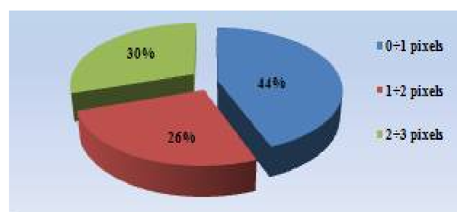


Fig. 9. The error repartition of the building detail points image coordinates

In the case of the distribution of medium angles between the projection rays used to calculate the detail points image coordinates, in Fig. 10 it is shown a chart based on the angle values grouped in intervals of 20°. The angles between the projection rays ranges between 6°16'35" and 89°23'51", with an average of 52°69'93".

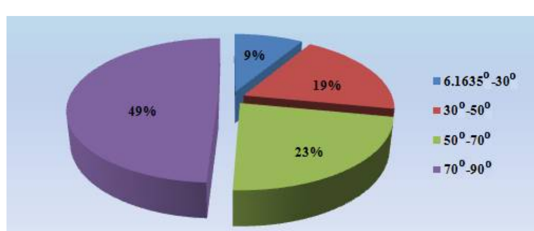


Fig. 10. The repartition of the angles between the projection rays used in points coordinates computation, based on digital images

4. Conclusions

Computerised 3D models have become part of peoples everyday lives. The problem of realistic 3D buildings model creation, is met in various domains of activity such as city planning, architecture and preservation, the requirements of the users being minors.

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.

The 3D reconstruction, modelling, documentation, monitoring and visualization of buildings can be realized using photogrammetric methods, with a relative good accuracy.

In special situations, where it isn't possible the acquisition of photos in ideal conditions, it can be used and it is recommended the fusion between digital images and total station measurments for 3D digital buildings model creation.

After comparing the spatial coordinates (X, Y, H) of 20 characteristic points of the 3D building model created using the "PhotoModeler" software, with the ones measured with the total station, the cumulative root mean square error was **of 15,2 cm**.

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.

In particular cases, where it is impossible to take photos in ideal conditions, this proposed method of fusioning the two different data information: digital images and total station measurements is an adequate solution in creating 3D building models with a good accuracy.

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