

CREATING AN INTERIOR 3D MODEL OF A CHURCH

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Abstract: *The paper deals with the 3D modelling based on photos. The target object is an interior space of a church. The photos were taken with a DJI Phantom Advanced UAV. Since the GPS receiver is not available inside buildings, the photos were taken in manual mode. In order to organize the shooting positions into vertical strips, the photos were taken from three different stations from different vertical positions. The 3D model was built with Agisoft PhotoScan software. The camera calibration was carried out prior the processing to ensure a higher accuracy. The scale of the model was setup by reference distances and points. The experiments showed us, that the created model is suitable not only for demonstration and artistic purposes, but for engineering measurements as well.*

Keywords: *UAS, 3D modelling, error assessment*

1. Introduction

1.1. Short summary of completed tasks

For testing, the interior of a church was used; the photos were taken at manual mode by vertical arrangement of expositions. On the walls several control points were measured by a total station geodetic instrument. The images were processed in Agisoft PhotoScan modeller software. As a result, the 3D model was transformed into the coordinate system of control points. The R.M.S. accuracy of the model was around 7 mm.

1.2. Short history of the chosen church

The Saint Stephen Cathedral was built in its present state around 1230 A.D. On the same place Géza (945-997 A.D.) the Grand Prince of Hungary built up the first Hungarian church. During the Turkish occupation it was used as a mosque and was rebuilt in 1702 by the Jesuit convent. The now known Cathedral was created by the help and order of Queen Maria Theresa. The Episcopate of Székesfehérvár was founded in 1777 and in 1938 the church became 'Basilica minor'[2].



Fig. 1. Cathedral Basilica of St. Stephen the King (Székesfehérvár)

1.3. Geodetic measurements

The measurement of control points was done by a Sokkia SET230 total station. The measurement was done from three points. These points were located in 3.5 metres distance from each other and all the points were visible from the other two. The measurement was arranged in local system.

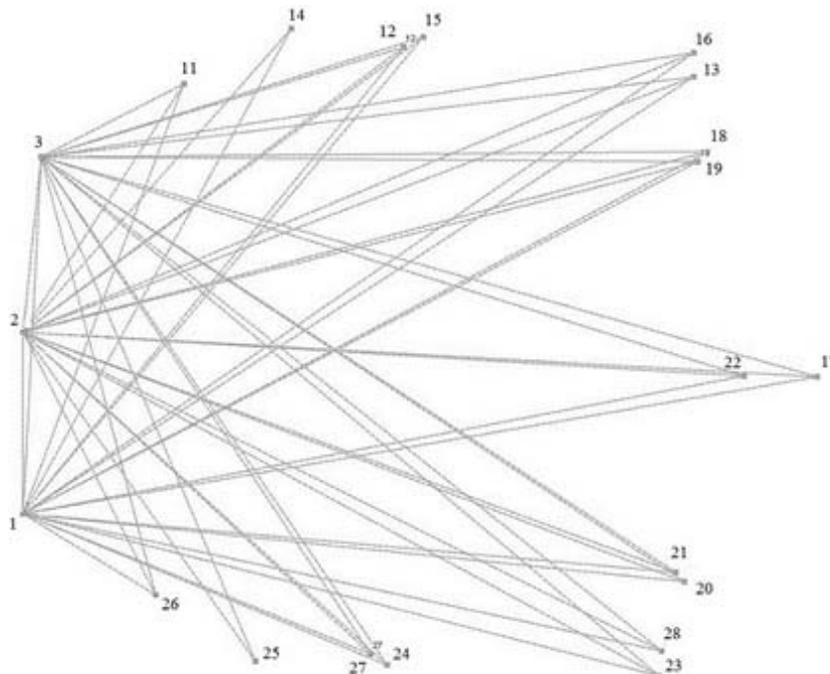


Fig. 2. Local geodetic network of control points

The adjustment and calculation of control points was carried out by GeoCalc software. The results are in Table I.

Table I. Adjusted coordinates of control points.

Number of points	Y [m]	X [m]	Z [m]
11	10003.103	2008.357	12.568
12	10007.346	2009.069	12.175
13	10012.938	2008.496	12.869
14	10005.172	2009.434	16.178
15	10007.724	2009.269	15.840
16	10012.938	2008.973	17.853
17	10015.325	2002.673	25.008
18	10013.224	2007.038	20.766
19	10013.019	2006.854	12.884
20	10012.767	1998.692	20.742
21	10012.590	1998.869	12.887
22	10013.920	2002.685	13.651
23	10012.286	1996.855	17.880
24	10007.025	1997.063	15.859
25	10004.485	1997.136	16.160
26	10002.552	1998.425	12.577
27	10006.709	1997.272	12.154
28	10012.327	1997.335	12.889

2. Camera calibration

Agisoft PhotoScan has a camera calibration module that allows making calculations based on amateur camera shots as well. Using amateur cameras, we do not know the internal data so we cannot eliminate the distortions of images.

Agisoft PhotoScan can calculate the following parameters for camera calibration:

1. f_x, f_y : focal length measured in pixels with x and y components,
2. c_x, c_y : coordinates of principal point (the where the camera axis goes through the image plane),
3. b_1, b_2 : skew parameters,
4. k_1, k_2, k_3, k_4 : parameters of the function describing the radial distortion,
5. p_1, p_2, p_3, p_4 : parameters of the function describing the tangential distortion [3].

To eliminate distortions, in addition to the above parameters, the program uses the following parameters:

- X, Y, Z – point coordinates in local system,
- u, v – pixels coordinates of the projected point,
- f – focal length,
- w, h – width and height of the image in pixels [3].

Using these quantities, actual corrections can be calculated. The results are also shown in a correlation matrix, in which the strength of the linear relationships between the parameters can be examined. The correlation can be between -1 and +1, with 0 the two variables are completely independent of each other [1]. First, we included all the parameters in the calculations, but there was a large correlation between some parameters, therefore we continued the calculations only with parameters of $c_x, c_y, k_1, k_2, k_3, p_1, p_2$. The parameters and the correlation coefficients are shown in Table II.

Table II. Camera calibration parameters and their correlation coefficients

	Érték	Hiba	F	Cx	Cy	K1	K2	P1	P2
K3	0.00955131								
F	2304.51	0.032	1.00	0.01	-0.22	0.10	0.24	0.02	-0.20
Cx	18.1706	0.052		1.00	-0.01	0.06	-0.04	0.95	-0.02
Cy	15.7252	0.098			1.00	-0.08	-0.02	-0.01	0.97
K1	-0.00987642	2.1e-05				1.00	-0.89	0.06	-0.06
K2	0.00456523	2.2e-05					1.00	-0.03	-0.03
P1	0.000534359	6.9e-06						1.00	-0.01
P2	0.000983596	9.8e-06							1.00

In Fig. 3 and 5 we can see the distortion vectors before and after the camera calibration. As we can notice, the camera calibration was very effective resulting around 1 pixel residuals of distortion vectors.

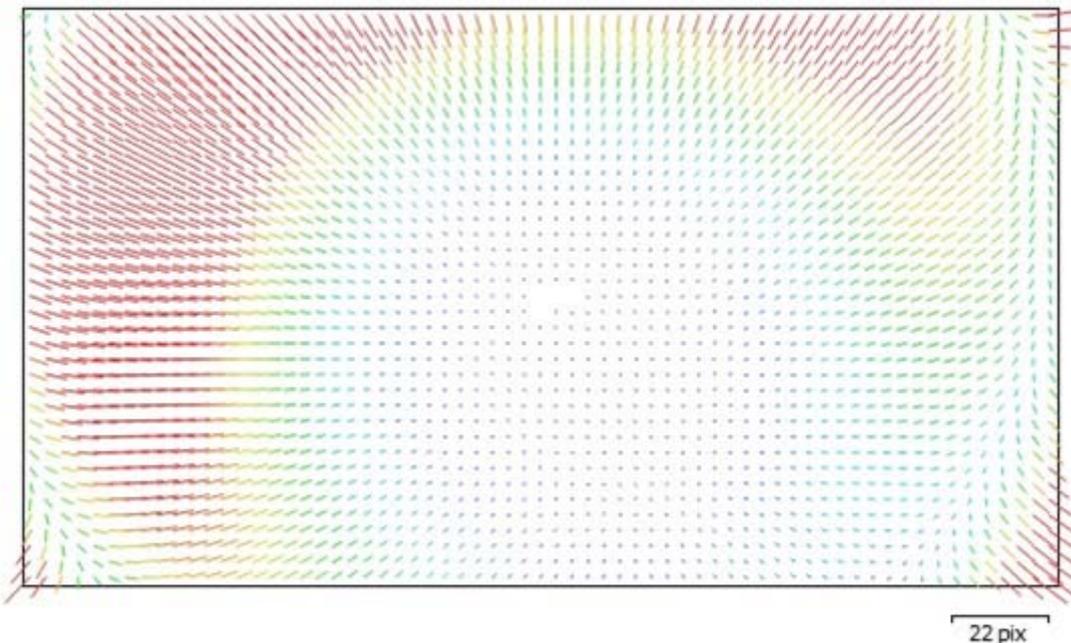


Fig. 3. Distortion before camera calibration

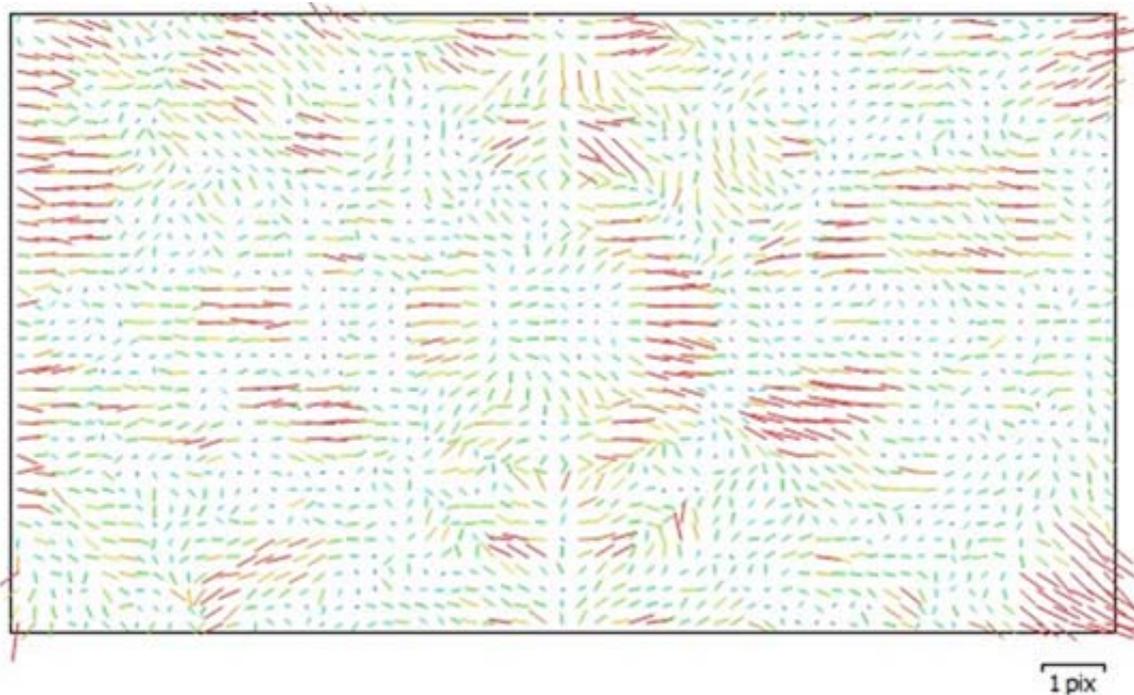


Fig. 4. Residuals of distortion after camera calibration

3. Phantom DJI 3

3.1. Technical data

Our Faculty has a DJI Phantom 3 Advanced aircraft (Fig. 5.). This UAV is available from the middle of 2015 and has more new features e.g. safer indoor use. The whole equipment is 1280 grams and its maximum ascend speed is 5 km/h and maximum horizontal speed is around 45 km/h. The UAV is equipped with GPS/Glonass receiver and has a precise 3-axis gimbal for good performance. The maximum operating range is more than 2 kilometres and the 4480 mAh LiPo battery operates for 22 minutes per charges.

Autopilot and 'GO HOME' function is available at any time or at less than 20 percent battery operation time. During flight an almost real time video (latency is 220 ms) is available thanks to DJI's Lightbridge technology.

The on board camera is a Sony EXMOR 1/2.3" camera which has 12.4 million effective pixels (the total pixels are 12.76 millions). The lens has a FOV of 94° with 20 mm focal length (35 mm format equivalent) and with f/2.8. The ISO range is 100-3200 for video recording and 100-1600 for photos. The shutter speed varies between 8 and 1/8000 seconds.

A new technology helps to fly safe indoor as the UAV is equipped with ultrasound sensors. The still photography modes contains single shot, burst shooting (3/5/7 shots), auto exposure and time lapse. The video mode contains 2.7K, FHD and HD.

The DJI GO application is available for IOS and Android. We use this device with Samsung Galaxy3 8" tablet.



Fig. 5. DJI Phantom 3 Advanced UAS (source: DJI.com)

3.2. Taking Photos

The great advantage of UAVs is the easy handling capability. Using the controller need great practice but not serious technical knowledge thanks to built in stabilizers, GNSS, etc. This supporting equipment is effective only in open air. Controlling the UAS become difficult inside the buildings because of the lack of GNSS techniques.

First the flight location was determined. The pictures were taken around the main altar from level zero up to 12 metres. Four locations were used during the flight, three locations as a triangle and the fourth location enabled us a wider view.

The photo taking method was the following:

- photos were taken meter by meter higher in every location up to 12 metres as the UAV position could be estimated more or less precisely the naked eye
- three photos were taken in all the first three locations in every height when the camera axis looked right centre and left
- differences between the camera axis were approximately 45 degrees
- only one picture was taken with centre axis in every height on the fourth location
- extreme caution was necessary due to the lack of stabilisation systems and the special environment

The flight height were measured by the built in ultrasonic sensors of the UAV. The live camera picture was used for navigation with the help of external observer. The DJI GO application was used for flight. The features of this application are:

- live HD camera view
- full camera control
- live broadcasting via internet
- instant video recording and editing
- map view and actual location view when GNSS is available [4].

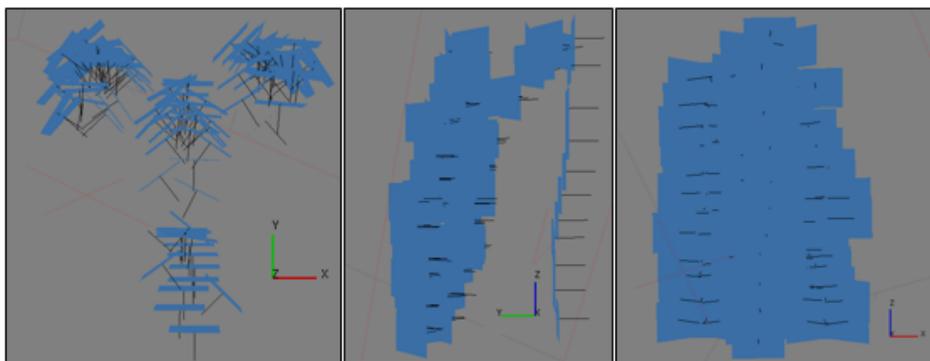


Fig. 6. Location of projection centres and photos from front and side view

Figure 6 shows that the four locations were not stable and the pictures were taken in a 2 metres distance circle. 123 pictures were taken all together and the flight time was shorter than 20 minutes.

4. 3D modelling

4.1. Modelling in Agisoft PhotoScan

For the first step image matching and orientation were necessary to be done. As a result a rare point cloud was created showing the common points of the pictures.

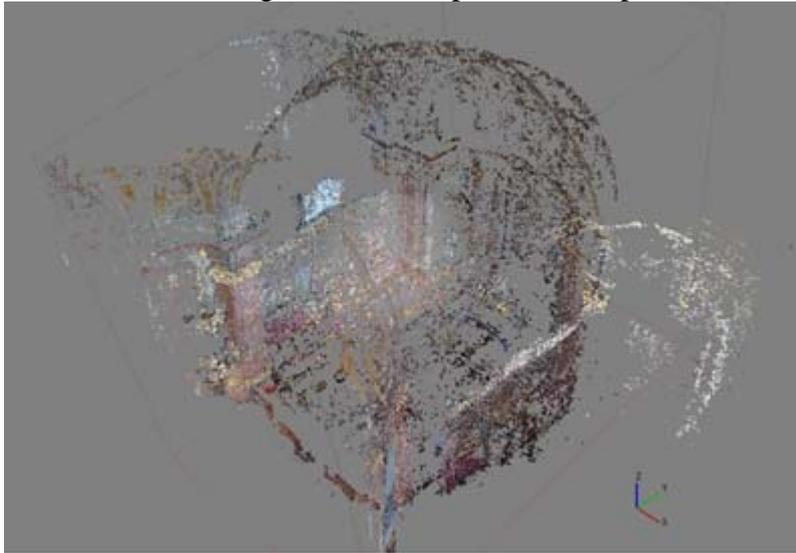


Fig. 7. The rare point cloud

Next step was the creation of the dense point cloud which can be found in the Workflow – Build Dense Cloud menu. Here you can determine the quality of point cloud and the method of deep filtering. After more than 42 hours of computer work the point cloud contains 52.5 million points and can be seen as a final model. But after zoom function deficiencies and wrong points can be seen. The Free Form Selection and delete function can improve these problems.

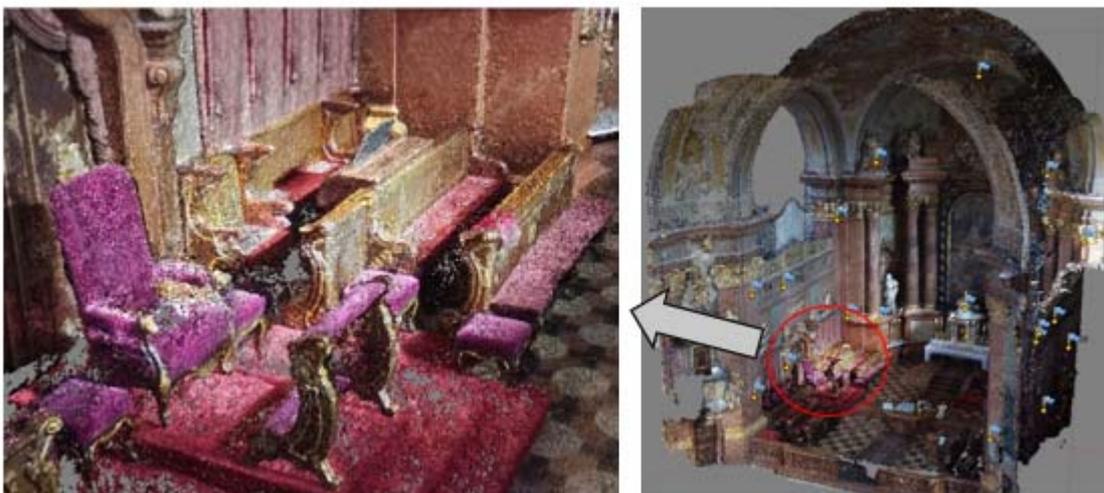


Fig. 8. Dense point cloud

A surface model, also called as ‘mesh’ must be created in order to hide the gaps between points and the result of this process is a TIN model.

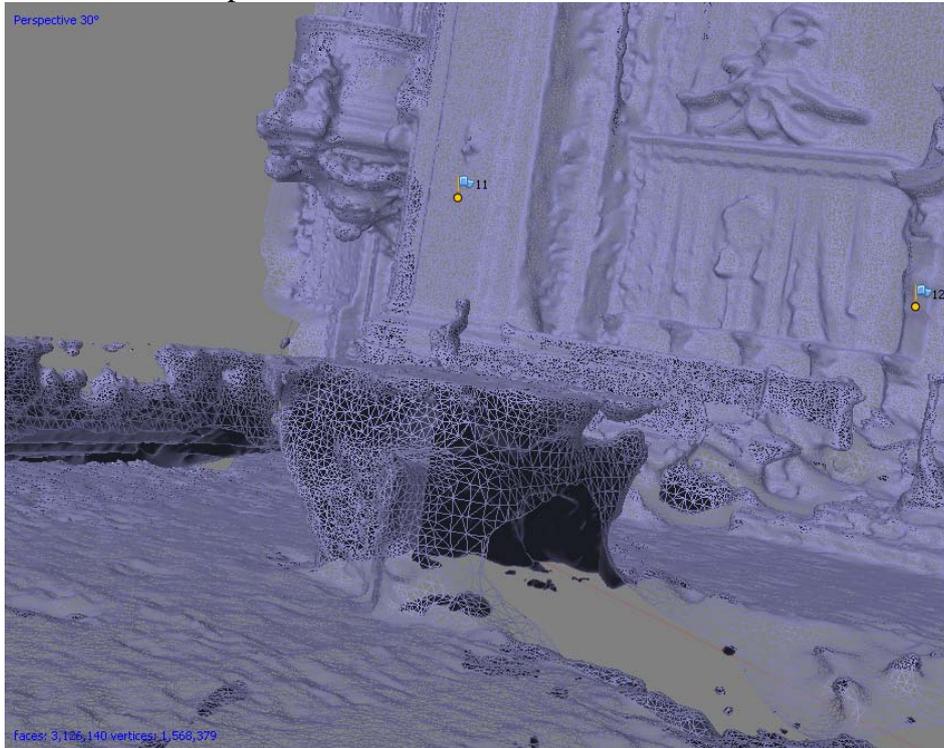


Fig. 9. TIN model

The model area contains large scale patches where no points can be found. These areas are empty on the surface model, too. The Close Holes function can hide these areas but it also modifies geometry thus it was not applied during the process.

Figure 10 shows that although the points of the dense point cloud are in their right place (left side) there are not enough points for exact visualisation.



Fig. 10. Errors in the surface model

The Build Texture function matches the photographic picture to the surface model and makes minor colour corrections for improvement. The better the photographic pictures the better the final result is.

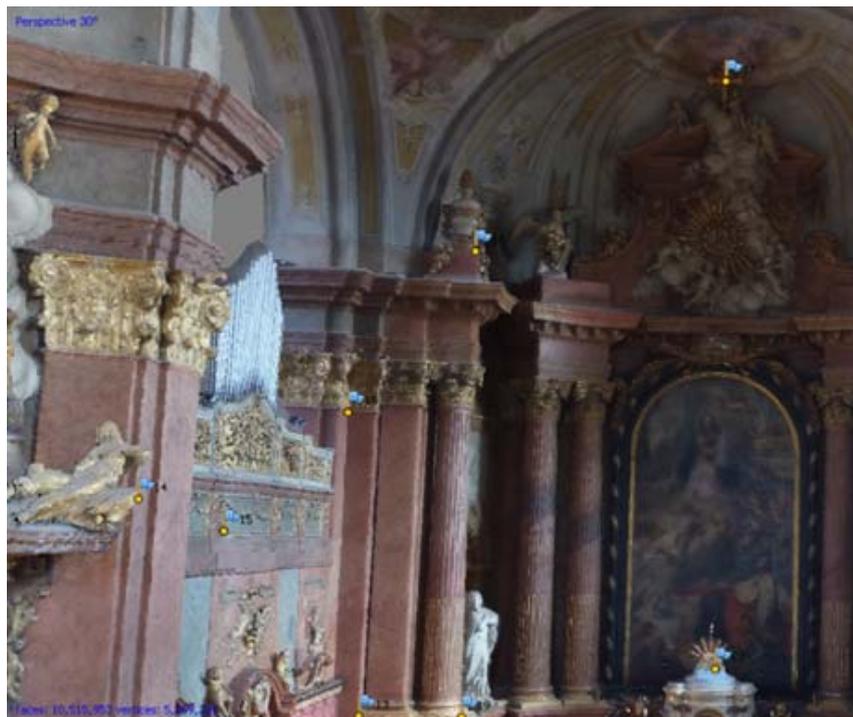


Fig. 11. Final model after texture building

4.2. Accuracy assessment

In Agisoft PhotoScan the control point can be marked in the model using the *Place Marker* function. In all 109 images the control point were marked and the software inside *Reference* tab we can activate the *Show errors* button which calculates the residuals in pixels. After eliminating three points (17, 19, 20) with large errors, we received the errors indicated in table III. Finally the model's standard deviation was around 7 millimetres.

Table III. Residuals of control points

Marker	Control points				Pointing error (pixel)
	X deviation (cm)	Y deviation (cm)	Z deviation (cm)	Σ (cm)	
11	-0.648713	-0.143921	-0.0890916	0.670432	1.530
12	-0.349716	0.181837	0.103978	0.407649	0.776
13	0.501929	-0.332492	0.603815	0.852688	0.953
14	0.527996	-0.126353	0.0172554	0.543178	1.180
15	-0.256274	-0.501965	0.176916	0.590716	1.546
16	0.74533	-0.477372	0.276792	0.92737	0.856
18	-0.265966	-0.055927	-1.02812	1.06344	1.894
21	0.429024	0.596053	-0.462721	0.868016	1.975
22	-0.274244	0.888113	-0.485914	1.04884	0.881
23	-0.446857	-0.25243	0.171467	0.541112	1.423
24	0.515845	0.160912	-0.418316	0.683357	1.843
25	-0.466935	0.159581	0.422836	0.649834	1.684
26	-0.176164	-0.153525	-0.110897	0.258654	1.227

27	0.141054	-0.0447053	-0.162665	0.219897	0.981
28	0.411649	0.261574	0.785084	0.924247	3.716
Total	0.441908	0.36664	0.44997	0.729507	1.717

4.3. Summary of Results and conclusions

The task was formulated in the April of 2017, and we could start the measurements in September, after choosing the best possible site. We needed to get photos taken by an UAV, and we needed to do a geodetic survey to have data for an accuracy check of the 3D model. The photos were taken by using a DJI Phantom 3 UAV, and we used a Sokkia SET230 total station with its necessary accessories for the geodetic surveying. The UAV flight took place in 4 setups, in different heights and towards 3 separate directions. At the end of the day, 123 photos were taken, 109 of them were used for generating the model.

In the geodetic survey we used 3 instrument setups, and we chose 18 control points on the site to measure. We took the measurements with extra care, in a specific way to be able to create a network and adjust errors at the same time. In order to minimize instrument errors in the surveying, we measured each points at twice permits. The mean error of the created network is 1/15050, which is acceptable for the accuracy requirement that we set to be 1 cm. The deviation of coordinates of each points in the network are far less than 1 cm.

The 3D model was generated by Agisoft PhotoScan, which is able to do an accuracy test by using the point coordinates calculated from the geodetic survey. After placing the point markers, the RMS error of the model happened to be about 7 millimetres. This RMS error covers the inaccurate marker placings and the modelling errors by the program itself. Considering the circumstances, the marker placing errors are more likely to be present in this RMS error, hence the program can be used reliably. Examining the errors of modelling and measuring, the task was completed successfully in our opinion, the technology can be used well in 3D modelling of interior spaces, in case of reduced accuracy requirements.

5. References

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