Report

Potential analysis of image based methods for deformation monitoring, with special regard on the comparison of different image processing software

Part 2-2

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Declaration of Authorship

„I declare in lieu of oath that this thesis is entirely my own work except where otherwise indicated. The presence of quoted or paraphrased material has been clearly signaled and all sources have been referred. The thesis has not been submitted for a degree at any other institution and has not been published yet."

Table of Contents

1 Introduction

Unmanned aerial vehicles (UAVs) together with consumer grade cameras are used for creation of 3D models (Fig. 1). Advantages of this method are very fast and cheap field work and automated data processing. The method is used in many different scenarios, such as: mapping, forest fires, damage surveying after floods and storms, where time is a critical factor for decision making and measures implementation.

UAVs have many advantages compared to traditional aerial surveying. The aircrafts are very small sized and compact packaging, consequently, the systems are transportable (they can easily fit in a small car or in a passenger airplane luggage) (“Blom” 2016).

Figure 1: Left: a copter GeoScan 401 and right: an aircraft GeoScan 201 (GeoScan 2016)

2 Field work

Place of surveying is a quarry near Leoben called “Pronat Steinbruch Preg” (Fig. 2). Preg is located between Kraubath and St. Lorenzen[1]. It is one of the leading quarries in Austria, which has hard stone. Size of the investigated area is about 160 x 180 and height is about 120 m (“Schwarzl-Gruppe” 2016).

Figure 2: Quarry **“Preg”**

The first step of the field work was the creation of a reference point network. For this task total station and GNSS-system was used. Special Ground Control Points (GCPs) were created (Fig. 3) and are mounted on the reference points.

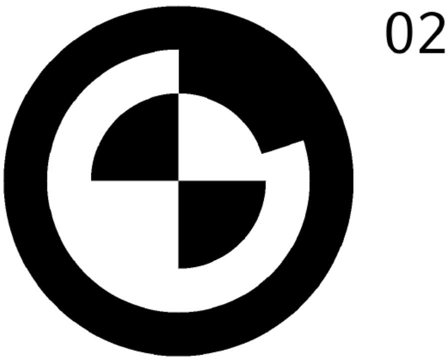

Figure 3: Ground Control Point (GCP) (Graz University of Technology)

[1] Latitude & Longitude (WGS84, decimal): 47.282865, 14.929528

The second step was surveying using the UAV of the Chair of Mining Engineering and Mineral Economics (“Tarot Frame”, flight controller “DJI NAZA M V2” and camera “Sony Alpha 6000”[2]) (Fig. 4). Before surveying camera was calibrated and needed parameters were defined and set.

Figure 4: UAV “Tarot Frame”, flight controller “DJI NAZA M V2” and camera “Sony Alpha 6000”

After these preparatory works, surveying can be started. While drone flew, camera took pictures every 3 seconds. Four flights were performed because battery time is about 7 minutes. The quarry was surveyed by UAV from several heights to mitigate the error propagation within the single height levels. Camera was set to nadir and was inclined for surveying of the highest points of the quarry surface. Duration of this step was about 2 hours. At last, all photos were transferred to computer for further processing.

[2] Focal length lens is fixed to 16 mm

3 Differences between the different data processing software

In this chapter differences between Agisoft PhotoScan Professional, I3D and Pix4Dmapper Pro are considered.

3.1 Agisoft PhotoScan Professional

Agisoft PhotoScan is a Russian photogrammetric software solution, which creates 3D models using digital images. The used version was 1.2.4 build 2399. The software has a very good interface, it supports 8 general languages.

Creation of a dense cloud is shown on flowchart in Figure 5. Through all processing a lot of different options, toolboxes and advanced parameters are available.

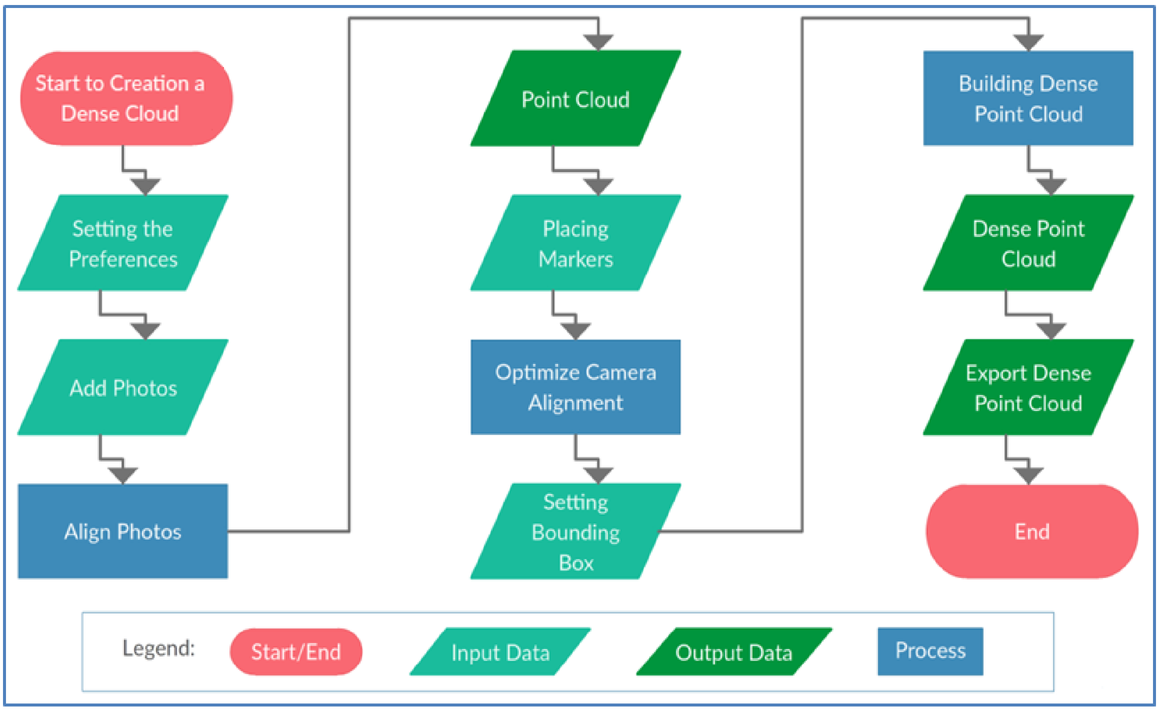

Figure 5: Flowchart of a dense cloud creation in PhotoScan

Manually placing of the markers is the biggest disadvantage of this software. PhotoScan can print and detect only own special markers (Fig. 6 left top). The

PhotoScan markers have white border, consequently, in a sunny weather it is not possible to recognize them (Fig. 6 right). Furthermore, PhotoScan cannot recognize external markers, therefore, all markers were put manually, which is a very time-consuming step

Figure 6: **Left top: a marker created in Agisoft PhotoScan and right: a photo from UAV with these markers (Montanuniversität Leoben)**

The results of manually putting markers are shown in Table 1. Markers №27, №29, №40 and №61 show the worst result concerning 3D position (16.7, 13.2, 16.4 and 11.5 cm respectively) and markers №75 and 71 show the worst result concerning an image position (2.82 and 1.23 pix respectively). All these markers are located on the edge of the scene or quarry respectively.

Marker	Error (cm)	X error (cm)	Y error (cm)	Z error (cm)	Error (pix)	Projections
1	2	3	4	5	6	7
27	16.7	-9.3	-12.1	-6.9	0.55	21
29	13.2	-11.6	-5.8	-2.3	0.39	24
31	6.7	-5.2	-3.7	-1.8	0.57	34
32	8	-0.7	-7.3	-3.1	0.39	29
33	8.1	7.4	2.8	-1.3	0.80	26
34	7.8	-3.1	7.1	0.5	0.68	28

1	2	3	4	5	6	7
35	4.2	-1	2.9	2.8	0.51	59
37	11.1	-9.3	5.2	3	0.54	79
38	3	1.1	-0.2	2.8	0.48	94
39	4.1	3.4	-1.1	2	0.41	59
40	16.4	8.6	-8.6	-11	0.25	8
50	4.9	-0.1	3.6	3.4	0.49	84
61	11.5	-5.5	-8.8	-4.9	0.30	28
62	7.5	6.9	0.6	-3	0.79	22
63	3.4	1.1	-2.4	-2.1	0.50	40
64	1.2	1	0.1	-0.7	0.50	40
65	8	-5.1	4.9	3.8	0.54	71
66	7.6	-5.7	3.1	4.1	0.46	97
67	7.6	-5	3.9	4.1	0.44	80
68	6.2	-1.6	5.9	1.4	0.56	41
69	8	-5.9	3.5	4.1	0.61	82
70	7.9	-6.3	3.2	3.6	0.40	84
71	8.5	-8.1	1.9	1.9	1.23	55
72	6.1	-5.5	1.4	2.3	0.66	71
73	5.3	-4.3	2.1	2.3	0.88	64
74	4.6	-4.2	0.9	1.5	0.65	58
75	7.3	-7.1	-1.8	0.6	2.82	48
76	5.4	-4.2	-3.4	-0.2	0.84	48
77	7.4	-5.4	3.5	3.7	0.50	99
78	9	-7.1	4.2	3.7	0.64	72
Total error (mean):	**8.3**	**5.8**	**4.8**	**3.6**	**-**	**-**
* check points			** transformation points			

Table 1: Markers accuracy

Before building dense point cloud it is possible to choose a quality: lowest, low, medium, high and ultra high, therefore, processing time and amount of points of dense cloud can be set.

In the experiment, quality of dense point cloud was chosen at a medium level. After processing, which took about 24 hours, 27.8 million points were created

(Fig. 7). This is far enough for comparison of different software products, and a higher density is not needed.

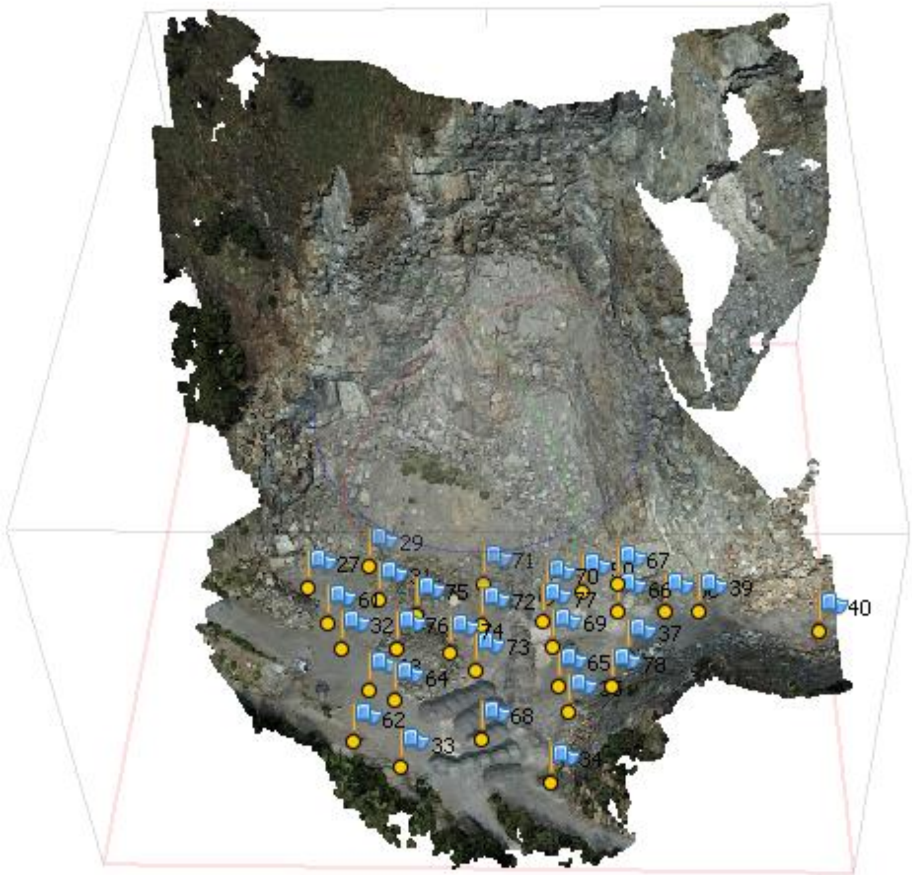

Figure 7: Dense Point Cloud

3.2 I3D

I3D is an Austrian photogrammetric software solution. It was created at Graz University of Technology at the Chair of Computer Graphics and Vision.

Algorithm of a dense cloud creation is almost the same like on the flowchart of processing in PhotoScan. All operations are performed automatically. However, the biggest disadvantage of I3D is the user interface. The software does not have a graphical interface and all commands are performed using command line.

I3D can detect markers automatically. Special markers (Fig. 8) are used in this software. The markers have black border, therefore, it is easy to detect them in all weather conditions.

Figure 8: Left top: a marker created for I3D (Graz University of Technology) and right: a photo from UAV with these markers (Montanuniversität Leoben)

After processing, which took about 24 hours, 28.5 million points were generated (Fig. 9). This number of points is almost equal to the PhotoScan result.

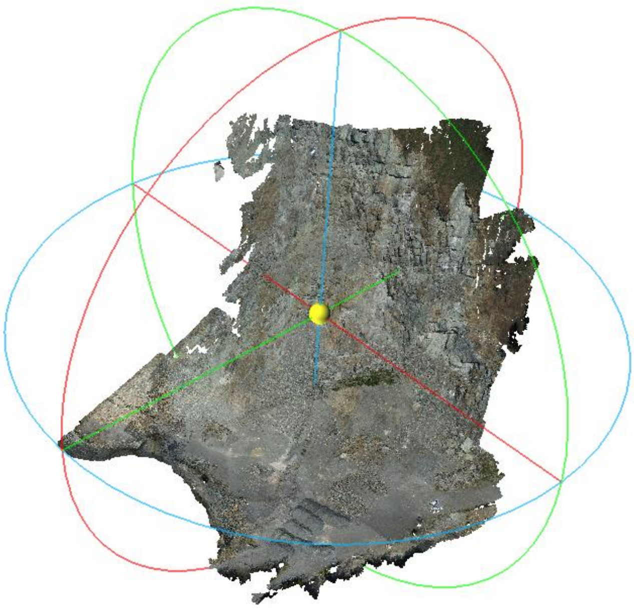

Figure 9: Dense Point Cloud (Visualized in CloudCompare V2)

3.3 Pix4Dmapper Pro

Pix4Dmapper Pro is a Swiss photogrammetric software solution, which creates 3D model using digital images. The used version was 2.1.53. The software has a very good interface, it supports 6 general languages.

Data processing in Pix4D consist of 3 parts: initial processing, point cloud and mesh and DSM, orthomosaic and Index. For comparison of the results only the two top steps are needed. The processing includes computing keypoints and matches, camera calibration and dense processing and took as well about 24 hours. After data processing a report was generated and software sends a message via e-mail, that it is successfully done.

As a result, only a partial cloud was generated, because the software used only nadir photo. Therefore, the wall of the quarry was not reconstructed (Fig. 10). For this reason, 3D cloud got from Pix4D was not used for further investigations.

Figure 10: Dense Point Cloud

3.4 Comparison between PhotoScan and I3D

Ground Control Points (GCPs) were used (Fig. 11) for transforming the initially non metric reconstruction and quantifying accuracy of the software. Coordinates of GCPs are shown in Annex 1 (accuracy is about 1 cm).

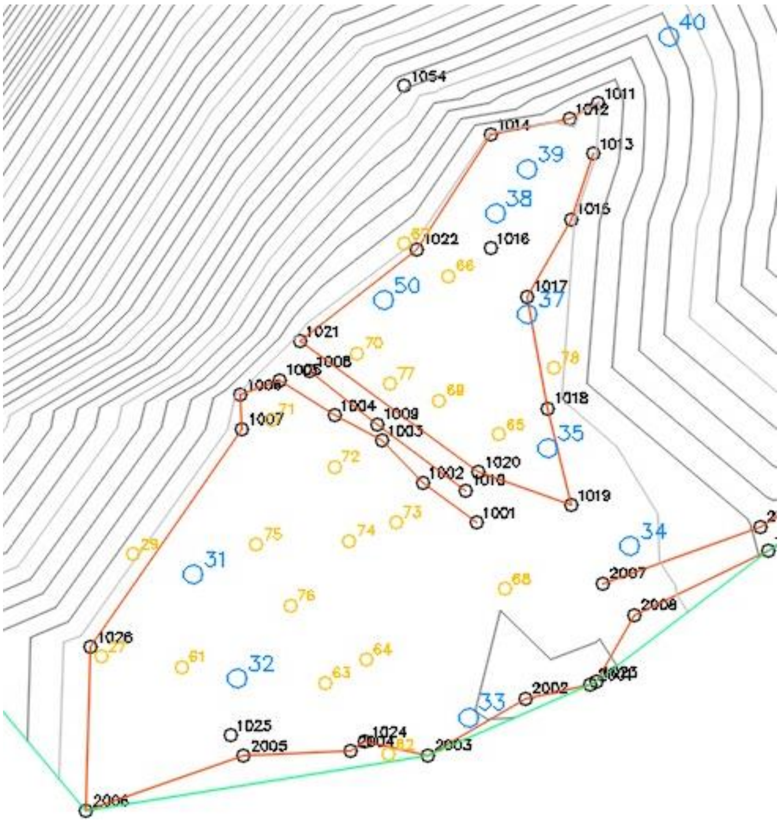

Figure 11: **Scheme of GCP (Montanuniversität Leoben)**

Check points (yellow points in Fig. 11) were used only for evaluation purpose, transformation points (blue in Fig. 11) were used for estimating the transformation parameters and evaluation. Coordinates of GCPs from I3D were compared to reference coordinates (Table 2).

№		I3D			Difference (I3D – Reference)				
№	**GCP**	**X, m**	**Y, m**	**H, m**	**vx, cm**	**vy, cm**	**vh, cm**	**v, cm**	**vv, cm2**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	**27**	239075.178	-106154.410	608.385	-5.6	-7.3	-6.8	**11.4**	130
2	**29**	239091.206	-106149.432	609.754	0.2	-6.9	-2.3	**7.3**	53
3	**31**	239088.099	-106139.996	608.924	0.9	-1.2	0.6	**1.6**	3
4	**32**	239071.859	-106133.225	609.553	-3.6	0.8	-1.5	**4.0**	16
5	**33**	239065.913	-106097.284	608.309	1.9	6.1	-0.4	**6.4**	41
6	**34**	239092.395	-106072.342	609.403	1.6	-3.5	-3.0	**4.9**	24
7	**35**	239107.661	-106085.091	608.928	-2.3	1.2	0.5	**2.6**	7
8	**37**	239128.353	-106088.114	610.517	-1.0	-2.8	-5.7	**6.4**	41
9	**38**	239144.004	-106093.072	609.393	-7.7	10.6	-11.0	**17.1**	292
10	**39**	239150.902	-106088.144	609.527	-10.3	13.6	-17.5	**24.5**	598
11	**50**	239130.561	-106110.456	609.216	0.6	8.9	-1.7	**9.1**	82
12	**61**	239073.633	-106141.800	609.231	-4.0	-3.5	-3.5	**6.4**	41
13	**62**	239060.056	-106109.605	609.076	0.9	6.3	-3.9	**7.5**	56

1	2	3	4	5	6	7	8	9	10
14	63	239071.186	-106119.520	609.333	-0.9	2.2	-0.2	2.4	6
15	64	239074.833	-106113.137	608.845	0.8	1.9	1.9	2.8	8
16	65	239109.732	-106092.547	608.978	0.5	-1.8	1.8	2.6	7
17	66	239134.389	-106100.281	609.490	-2.0	3.1	-3.0	4.8	23
18	67	239139.347	-106107.205	609.232	-0.3	5.3	-5.1	7.4	54
19	68	239085.778	-106091.606	609.636	3.5	-0.8	1.2	3.8	14
20	69	239115.061	-106101.824	610.189	0.7	-0.2	2.9	3.0	9
21	70	239122.440	-106114.575	609.037	1.7	1.4	2.1	3.0	9
22	71	239112.124	-106127.898	608.828	3.3	-0.3	4.4	5.5	30
23	72	239104.759	-106118.172	608.581	1.4	-0.5	4.7	4.9	24
24	73	239096.168	-106108.604	608.327	1.3	-1.6	5.2	5.6	31
25	74	239093.312	-106115.763	609.523	1.3	-0.6	4.6	4.8	23
26	75	239092.702	-106130.272	609.290	0.9	-2.2	4.0	4.6	21
27	76	239083.177	-106125.019	609.632	-1.1	-1.6	2.5	3.2	10
28	77	239117.704	-106109.475	608.841	1.3	0.9	3.1	3.4	12
29	78	239120.079	-106084.059	609.429	-2.5	-2.9	-2.4	4.6	21
								m =	7.6 cm

Table 2: Analysis of a data processing accuracy using I3D

The Mean Square Error (MSE) was calculated using the formula 1:

$$m = \sqrt{\frac{[vv]}{n}}; \tag{1}$$

where *v* is a difference between coordinates of I3D and reference data and *n* is the number of points.

As a result, the MSE between all markers is 7.6 cm. GCP № 38 and 39 show the biggest values (17.1 and 24.5 cm respectively). The same analysis was done for evaluating the data processing in Agisoft PhotoScan (Table 3).

№		PhotoScan			Difference (PhotoScan – Reference)				
№	GCP	X, m	Y, m	H, m	vx, cm	vy, cm	vh, cm	v, cm	vv, cm2
1	2	3	4	5	6	7	8	9	10
1	27	239075.113	-106154.430	608.384	12.1	9.3	6.9	16.7	280
2	29	239091.146	-106149.479	609.754	5.8	11.6	2.3	13.2	174
3	31	239088.053	-106140.036	608.900	3.7	5.2	1.8	6.7	44
4	32	239071.822	-106133.240	609.537	7.3	0.7	3.1	8.0	64
5	33	239065.922	-106097.271	608.300	-2.8	-7.4	1.3	8.1	65
6	34	239092.450	-106072.338	609.438	-7.1	3.1	-0.5	7.8	61
7	35	239107.713	-106085.113	608.951	-2.9	1.0	-2.8	4.2	17
8	37	239128.415	-106088.179	610.604	-5.2	9.3	-3.0	11.1	124
9	38	239144.079	-106093.167	609.531	0.2	-1.1	-2.8	3.0	9

1	2	3	4	5	6	7	8	9	10
10	39	239150.994	-106088.246	609.722	1.1	-3.4	-2.0	4.1	17
11	40	239171.327	-106066.166	609.870	8.6	-8.6	11.0	16.4	268
12	50	239130.591	-106110.546	609.267	-3.6	0.1	-3.4	4.9	24
13	61	239073.585	-106141.820	609.217	8.8	5.5	4.9	11.5	132
14	62	239060.053	-106109.599	609.085	-0.6	-6.9	3.0	7.5	57
15	63	239071.171	-106119.531	609.314	2.4	-1.1	2.1	3.4	11
16	64	239074.826	-106113.146	608.819	-0.1	-1.0	0.7	1.2	1.5
17	65	239109.776	-106092.580	608.998	-4.9	5.1	-3.8	8.0	64
18	66	239134.440	-106100.369	609.561	-3.1	5.7	-4.1	7.6	58
19	67	239139.389	-106107.308	609.324	-3.9	5.0	-4.1	7.6	57
20	68	239085.802	-106091.614	609.638	-5.9	1.6	-1.4	6.2	39
21	69	239115.089	-106101.881	610.201	-3.5	5.9	-4.1	8.0	64
22	70	239122.455	-106114.652	609.052	-3.2	6.3	-3.6	7.9	63
23	71	239112.110	-106127.976	608.803	-1.9	8.1	-1.9	8.5	73
24	72	239104.759	-106118.222	608.557	-1.4	5.5	-2.3	6.1	38
25	73	239096.176	-106108.631	608.298	-2.1	4.3	-2.3	5.3	29
26	74	239093.308	-106115.799	609.492	-0.9	4.2	-1.5	4.6	21
27	75	239092.675	-106130.321	609.256	1.8	7.1	-0.6	7.3	54
28	76	239083.154	-106125.045	609.605	3.4	4.2	0.2	5.4	29
29	77	239117.726	-106109.538	608.847	-3.5	5.4	-3.7	7.4	55
30	78	239120.146	-106084.101	609.490	-4.2	7.1	-3.7	9.0	82
								m =	8.3 cm

Table 3: Analysis of a data processing accuracy using Agisoft

The result is almost the same – the MSE is 8.3 cm. GCP № 27 and 40 show the biggest difference to reference data (16.7 and 16.4 cm respectively). Therefore, it is possible to conclude, that GCPs with the biggest error values are located near to the edges of the GCPs' area. It can be seen very well in Figure 12.

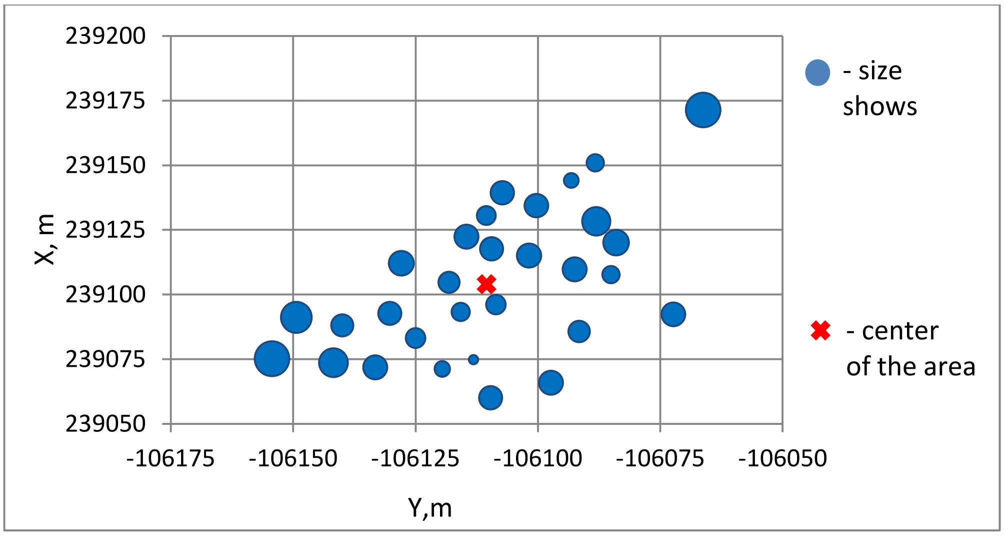

Figure 12: Differences between results of Agisoft and reference data

For analysing this hypothesis more deeply, distance between all GCPs and centre of GCPs' area is calculated. It is easy to solve, for example, using Searching Method (Listing of Visual Basic for Application [VBA] language is presented at Annex 2 and 3).

In Figure 13 PhotoScan results were used. Centre of GCP area is: X = 239103.59 m and Y = -106110.56 m. The distances between GCPs and centre of their area and differences between results of PhotoScan and reference data are known, therefore correlation between these two parameters can be easily found (Fig. 13).

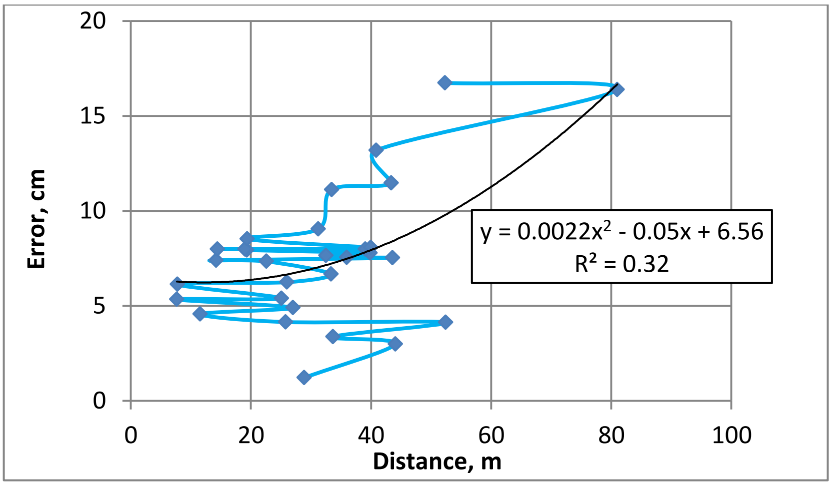

Figure 13: Influence between of the PhotoScan error and the distances between GCPs and GCP's centre

The determination factor shows that there is only partial influence (R^2 = 0.32, R = 0.56). Better results were got for I3D data (R^2 = 0.62, R = 0.78) (Fig. 14).

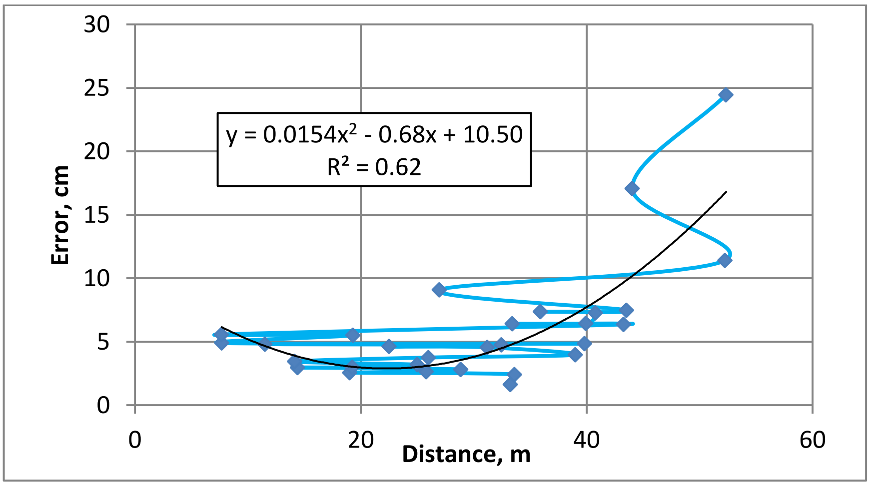

Figure 14: Influence between of the I3D error and the distances between GCPs and GCP's centre

The total differences between the two software products are shown in Table 4.

№		Difference (I3D – PhotoScan)				
№	**GCP**	**vx, cm**	**vy, cm**	**vh, cm**	**v, cm**	**vv, cm2**
1	**2**	**6**	**7**	**8**	**9**	**10**
1	**27**	6.5	2.0	0.1	**6.8**	46
2	**29**	6.0	4.7	0.0	**7.6**	58
3	**31**	4.6	4.0	2.4	**6.6**	42.9
1	**2**	**3**	**4**	**5**	**6**	**7**
4	**32**	3.7	1.6	1.6	**4.4**	19
5	**33**	-1.0	-1.3	0.9	**1.9**	3
6	**34**	-5.5	-0.4	-3.5	**6.5**	43
7	**35**	-5.2	2.2	-2.3	**6.1**	36.9
8	**37**	-6.3	6.5	-8.7	**12.5**	157
9	**38**	-7.5	9.5	-13.8	**18.3**	336
10	**39**	-9.2	10.2	-19.5	**23.9**	569
11	**40**	-	-	-	**-**	-
12	**50**	-2.9	9.0	-5.0	**10.7**	115
13	**61**	4.8	1.9	1.4	**5.4**	29
14	**62**	0.3	-0.5	-0.9	**1.1**	1
15	**63**	1.5	1.1	1.9	**2.6**	7
16	**64**	0.8	0.9	2.6	**2.9**	8.2
17	**65**	-4.4	3.3	-2.0	**5.9**	34.3
18	**66**	-5.2	8.8	-7.0	**12.4**	153
19	**67**	-4.2	10.3	-9.2	**14.4**	208
20	**68**	-2.4	0.8	-0.2	**2.6**	7
21	**69**	-2.9	5.6	-1.2	**6.5**	41.7
22	**70**	-1.5	7.7	-1.5	**8.0**	64
23	**71**	1.4	7.8	2.5	**8.3**	69
24	**72**	-0.1	5.0	2.4	**5.6**	31
25	**73**	-0.8	2.8	2.9	**4.1**	16
26	**74**	0.4	3.6	3.1	**4.8**	23
27	**75**	2.8	4.9	3.4	**6.6**	43
28	**76**	2.3	2.6	2.7	**4.4**	19
29	**77**	-2.2	6.3	-0.6	**6.7**	44
30	**78**	-6.7	4.2	-6.2	**10.0**	100
					m =	**9.0 cm**

Table 4: Differences of GCP coordinates between I3D and PhotoScan

Table 4 shows that the MSE between all markers is 9.0 cm. This MSE includes the error of two software products, therefore, it has bigger value then each error individually. GCP № 38 and 39 show the biggest values (18.3 and 23.9 cm respectively), because the influence of I3D error is very large there (17.1 and 24.5 cm respectively).

For computing differences between two dense clouds from PhotoScan and I3D, CloudCompare was used. CloudCompare is a software solution for processing and analysis of 3D point clouds. The result of comparison is shown in Figure 15.

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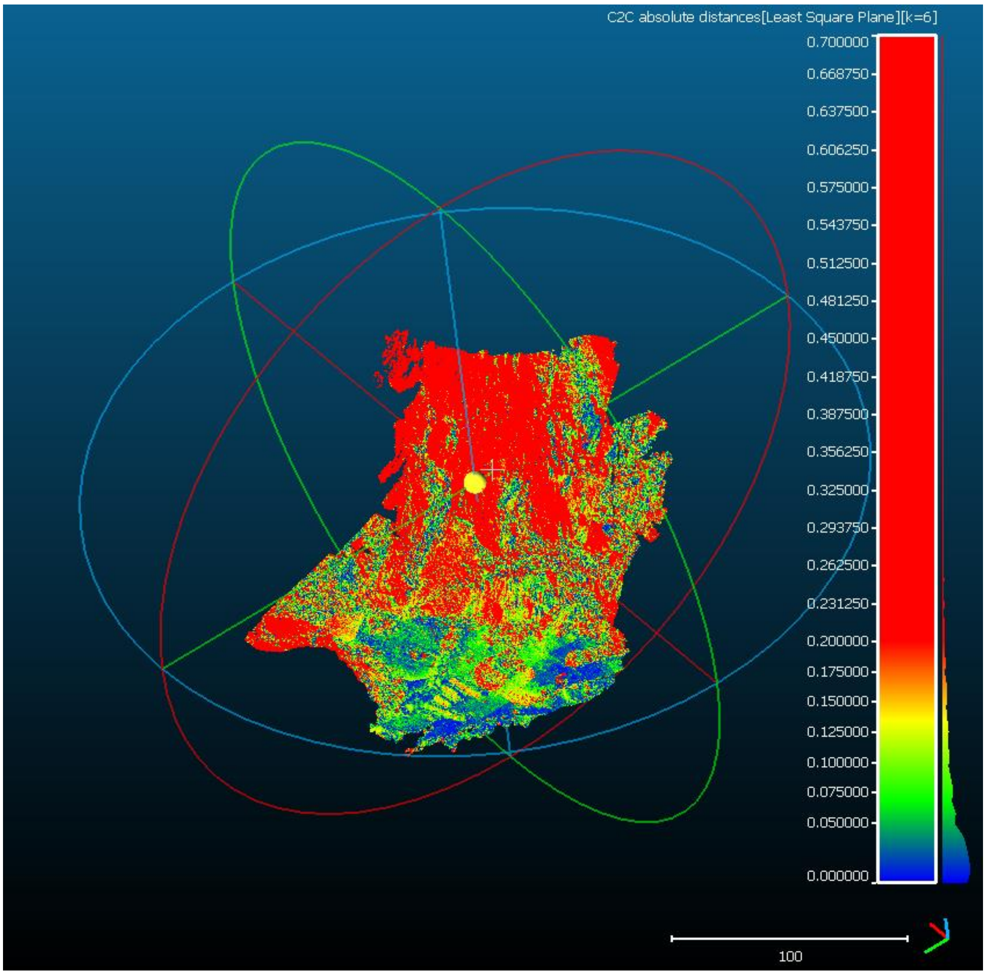

Figure 15: Differences between I3D and PhotoScan dense clouds

For better visualization the new cloud which shows the differences between two dense clouds of PhotoScan and I3D was divided into two clouds: bottom part and wall (Fig. 16). The wall has differences approximately between 0 – 50 cm and the bottom part is about 0-10 cm predominantly.

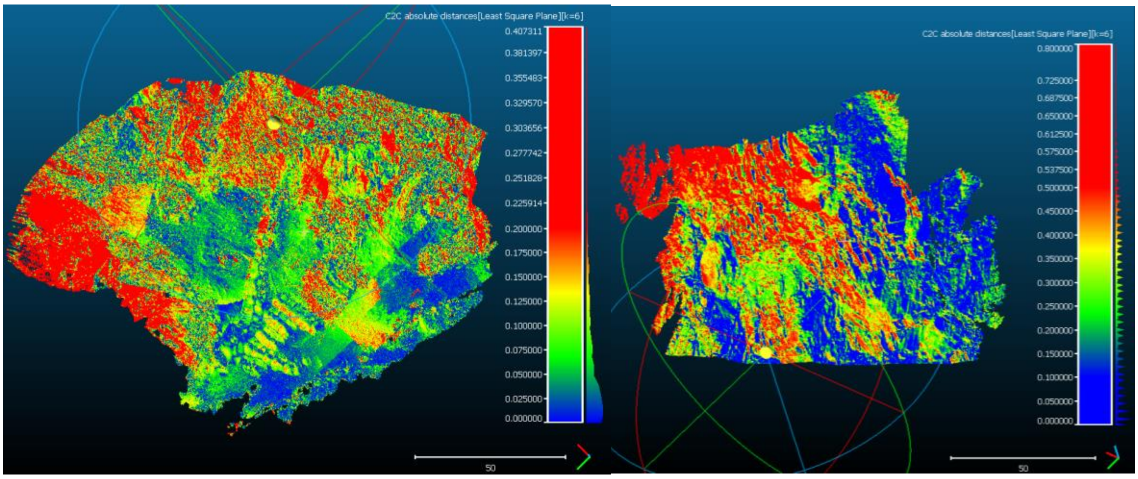

Figure 16: Differences between I3D and PhotoScan dense clouds; left: a bottom part and right: a wall

For analysing the systematic error more deeply one cloud was aligned to the second cloud using Least Square Method (LSM). Figure 17 shows the result of comparing these clouds. Analysis of the result does not show clear information about the systematic error. However, Figure. 17 shows that alignment is impossible to use, because the two clouds have the same coordinate system and results are getting worse compared to “external” alignment via Similarity Transform.

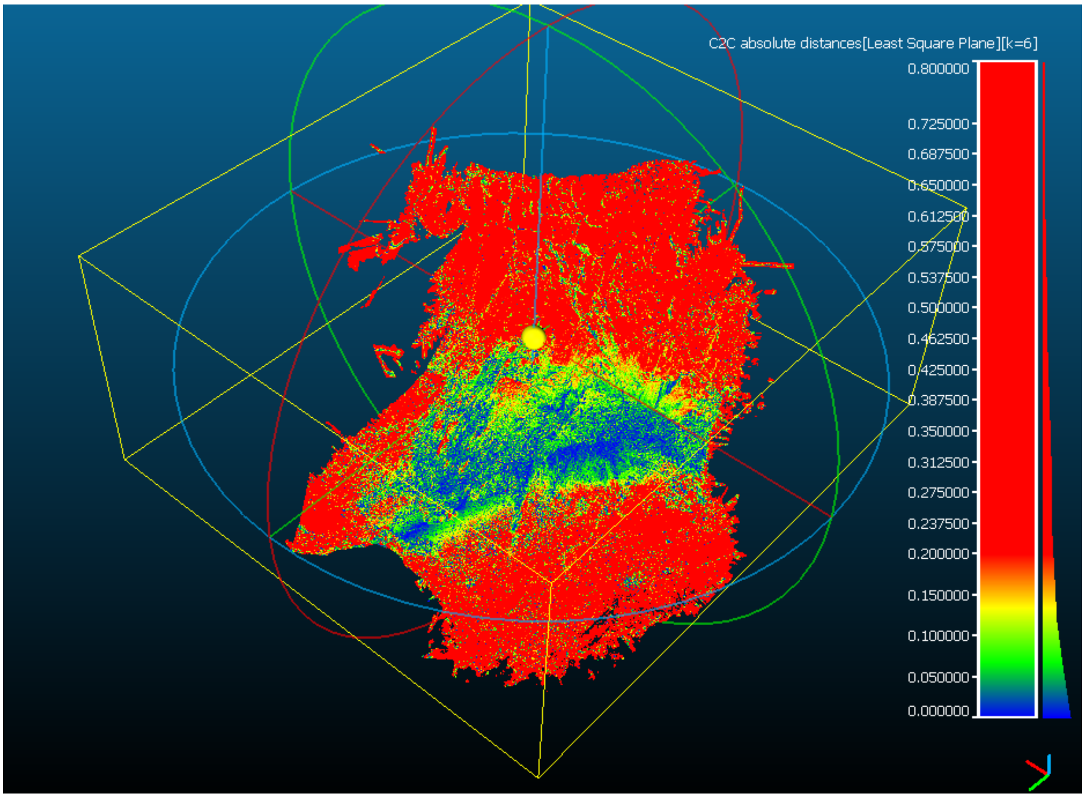

Figure 17: Differences between aligned dense clouds

For analysis of different quality parameters of building dense clouds in PhotoScan, the top part of quarry was used. The small area was chosen to decrease computation time throughout this experiment. Five dense clouds were created with the following quality parameters: ultrahigh, high, medium, low and lowest. The cloud with ultrahigh quality was assumed as the reference cloud. The other clouds were compared with this more accurate cloud in CloudCompare. The number of points in clouds with different quality is shown in Table 5.

Dense cloud quality	Number of points	Processing time, min
1	**2**	**3**
Ultrahigh	74 096 065	360
High	19 017 887	120
Medium	4 733 442	30
Low	1 156 296	10
Lowest	279 052	3

Table 5: Number of points using different dense cloud quality

The difference between clouds of ultrahigh and lowest quality is shown in Figure 18.

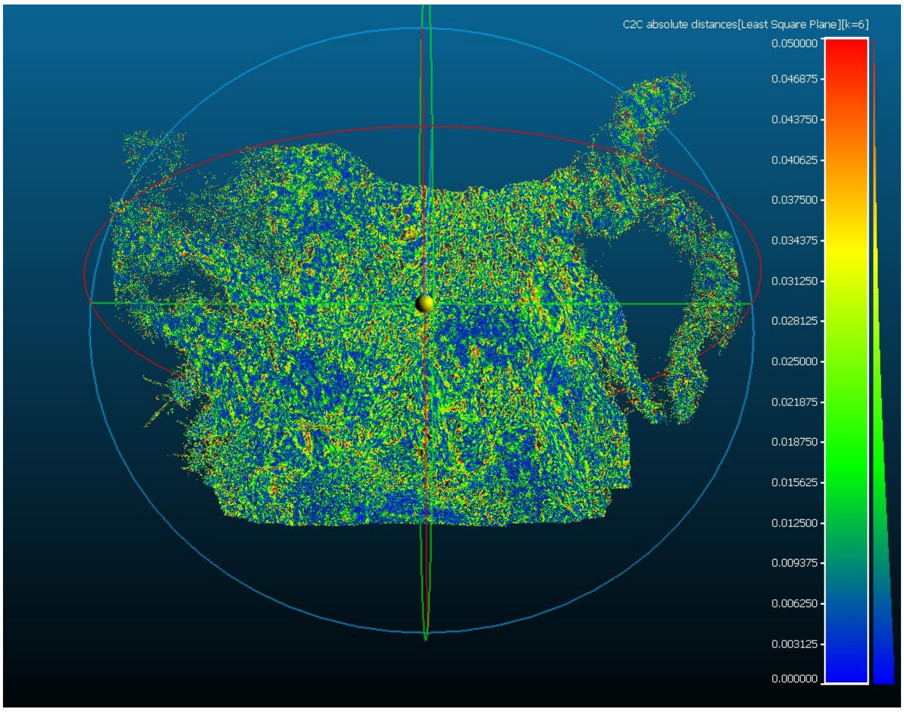

Figure 18: A difference between clouds of ultrahigh and lowest quality

Figure 18 shows that MSEs between these two clouds are not more than 5 cm mainly. For this reason, comparison between the best and the worst clouds was made. Differences between the ultrahigh quality and other quality are less than 5 cm. Experiments with other clouds confirmed this theory (Table 6).

Dense cloud quality	**Range of error (mainly), cm**
1	**2**
Ultrahigh	-
High	0 – 0.5
Medium	0 - 1.5
Low	0 - 2.5
Lowest	0 – 5.0

Table 6: Range of error depends of dense cloud quality building

4 Conclusion

A quarry called “Pronat Steinbruch Preg” was measured in 2015 using UAV technology in conjunction with a consumer grade camera. After field work, dense 3D point clouds were created out of the image information. Sequence of data processing was:

- Acquisition works (setting the preferences and add photos);
- calibration and alignment of the photos;
- placing markers;
- optimizing camera alignment;
- building a dense point cloud.

Data processing was done using different software solutions: Agisoft PhotoScan, I3D and Pix4D. However, Pix4D could not process inclined photos, therefore, the results of this software were not further analysed. Advantages and disadvantages are shown in the Table 7 in a more clear way.

№	**Parameter**	**PhotoScan**	**I3D**	**Pix4D**
1	**2**	**3**	**4**	**5**
1	Processing time, hours	24	24	24
2	Graphical interface	+	-	+
3	Processing of inclined photos	+	+	-
4	Automatically detecting markers	-/+	+	+
5	Camera calibration	+	+	+

Table 7: Comparison of image processing software

Analysis of the results show that MSE of data processing in I3D is 7.6 cm and in PhotoScan is 8.3 cm using GCPs. The GCPs located near to the edges of GCP’s area or scene respectively have the biggest value of error (factor of correlation reaches up to 78%).

Cloud comparison of the PhotoScan and I3D results was done using a software solution called CloudCompare. Results showed that the area with GCPs (bottom part of the quarry) has differences between 0-10 cm and, conversely, the area without GCPs (wall of the quarry) has differences between 0-50 cm.

Conventional methods have better accuracy than camera equipped UAVs, therefore, they are better suited for deformation monitoring (Table 8). According to Zubov (2012) soil slip has the biggest value of MSE, but the required error is still less than accuracy of UAV measurement in the present investigations.

Object	MSE of measuring deformation, mm
1	**2**
Construction on a rock	1
Construction on a soft surface	2
Construction on a very soft surface	5
Earthwork structure: Construction period Operational phase	 10 5
Soil slip	30-50
Rockfall area	1-2

Table 8: MSE of measuring deformation depends of monitoring object (Zubov 2012)

However, UAV is used in many different scenarios, such as: mapping, forest fires, damage surveying after floods and storms, where time is a critical factor for decision making and measures implementation (“Blom” 2016).

5 Bibliography

Zubov, A.V.: Geodetic monitoring for building deformation (rus.), SPSMI(TU), 2012, p. 56.

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“I3D“ software, http://www.icg.tugraz.at/, (28.07.2016)

“Pix4Dmapper Pro“ sofware, https://pix4d.com/, (28.07.2016)

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6 List of Figures

7 List of Tables

8 List of Abbreviations

GCP	Ground Control Point
LSM	Least Square Method
MSE	Mean Square Error
UAV	Unmanned Aerial Vehicle
VBA	Visual Basic for Application

Annex Table of Contents

Annex

1. Coordinates data of GCP:

Name	Y, m	X, m	H, m
1	2	3	4
27	-106154.337	239075.234	608.453
29	-106149.363	239091.204	609.777
31	-106139.984	239088.090	608.918
32	-106133.233	239071.895	609.568
33	-106097.345	239065.894	608.313
34	-106072.307	239092.379	609.433
35	-106085.103	239107.684	608.923
37	-106088.086	239128.363	610.574
38	-106093.178	239144.081	609.503
39	-106088.280	239151.005	609.702
40	-106066.252	239171.413	609.980
41	-106011.453	239171.484	650.845
42	-106009.890	239230.644	683.150
43	-106170.683	239282.279	704.245
44	-106126.303	239305.606	705.659
45	-106105.774	239311.046	710.371
47	-106153.558	239311.554	719.258
48	-106059.692	239283.820	710.347
50	-106110.545	239130.555	609.233
51	-106016.808	239195.264	655.063
52	-106019.076	239200.068	656.136
53	-106025.862	239211.722	657.278
54	-106038.340	239144.091	630.459
55	-106040.357	239149.072	630.632
56	-106033.302	239271.289	704.737
57	-106039.493	239275.589	707.030
58	-106088.611	239303.933	710.970
60	-106046.131	239276.793	708.883
61	-106141.765	239073.673	609.266
62	-106109.668	239060.047	609.115
63	-106119.542	239071.195	609.335
64	-106113.156	239074.825	608.826
65	-106092.529	239109.727	608.960
66	-106100.312	239134.409	609.520
67	-106107.258	239139.350	609.283

1	2	3	4
68	-106091.598	239085.743	609.624
69	-106101.822	239115.054	610.160
70	-106114.589	239122.423	609.016
71	-106127.895	239112.091	608.784
72	-106118.167	239104.745	608.534
73	-106108.588	239096.155	608.275
74	-106115.757	239093.299	609.477
75	-106130.250	239092.693	609.250
76	-106125.003	239083.188	609.607
77	-106109.484	239117.691	608.810
78	-106084.030	239120.104	609.453

2. Listing of searching method in VBA:

```
Sub Center_Finding()
' Center_Finding searches the centre of input cloud.
' Warning! Some calculations are done on the list of Excel.
' D. Beregovoi, 22-07-2016

MSE = Cells(37, 16) 'current MSE
step = Cells(5, 19) 'step of 1 iteration
t = Cells(8, 19) ' number of iterations

For i = 1 To t

' -------------------------------------------------------------
-
' Moving by X coordinate
MSE2 = MSE 'remember the current MSE
Cells(6, 19) = Cells(6, 19) + step 'cells(6,19) is current X
coordinate
MSE = Cells(37, 16)

'Cells(37, 16) is calculated on the list of Excel.
' It is a sum of square differences between current centre and
position of all markers.

If MSE > MSE2 Then Cells(6, 19) = Cells(6, 19) - 2 * step

' -------------------------------------------------------------
-
' Moving by Y coordinate

MSE2 = MSE
Cells(7, 19) = Cells(7, 19) + step 'cells(7,19) is current Y
coordinate
MSE = Cells(37, 16)

If MSE > MSE2 Then Cells(7, 19) = Cells(7, 19) - 2 * step


Next i

End Sub
```

3. List of Excel for searching the centre of the GCPs:

Comparing of Agisoft and Reference

№		Agisoft			Reference			Difference					Distance	
№	GCP	X, m	Y, m	H, m	X, m	Y, m	H, m	vx, cm	vy, cm	vh, cm	v, cm	vv, cm2	Distance, m	Sqr. Distance, m2
1	2	3	4	5	7	8	9	10	11	12	13	14	15	16
1	27	239075.113	-106154.430	608.384	239075.234	-106154.337	608.453	12.1	9.3	6.9	16.7	280	52.30	2736
2	29	239091.146	-106149.479	609.754	239091.204	-106149.363	609.777	5.8	11.6	2.3	13.2	174	40.86	1670
3	31	239088.053	-106140.036	608.900	239088.090	-106139.984	608.918	3.7	5.2	1.8	6.7	44	33.32	1110
4	32	239071.822	-106133.240	609.537	239071.895	-106133.233	609.568	7.3	0.7	3.1	8.0	64	39.03	1524
5	33	239065.922	-106097.271	608.300	239065.894	-106097.345	608.313	-2.8	-7.4	1.3	8.1	65	39.94	1595
6	34	239092.450	-106072.338	609.438	239092.379	-106072.307	609.433	-7.1	3.1	-0.5	7.8	61	39.81	1585
7	35	239107.713	-106085.113	608.951	239107.684	-106085.103	608.923	-2.9	1.0	-2.8	4.2	17	25.78	665
8	37	239128.415	-106088.179	610.604	239128.363	-106088.086	610.574	-5.2	9.3	-3.0	11.1	124	33.42	1117
9	38	239144.079	-106093.167	609.531	239144.081	-106093.178	609.503	0.2	-1.1	-2.8	3.0	9.0	44.07	1942
10	39	239150.994	-106088.246	609.722	239151.005	-106088.280	609.702	1.1	-3.4	-2.0	4.1	17	52.39	2745
11	40	239171.327	-106066.166	609.870	239171.413	-106066.252	609.980	8.6	-8.6	11.0	16.4	268	80.99	6559
12	50	239130.591	-106110.546	609.267	239130.555	-106110.545	609.233	-3.6	0.1	-3.4	4.9	24	27.00	729
13	61	239073.585	-106141.820	609.217	239073.673	-106141.765	609.266	8.8	5.5	4.9	11.5	132	43.33	1877
14	62	239060.053	-106109.599	609.085	239060.047	-106109.668	609.115	-0.6	-6.9	3.0	7.5	57	43.55	1896
15	63	239071.171	-106119.531	609.314	239071.195	-106119.542	609.335	2.4	-1.1	2.1	3.4	11	33.64	1131
16	64	239074.826	-106113.146	608.819	239074.825	-106113.156	608.826	-0.1	-1.0	0.7	1.2	1.5	28.88	834
17	65	239109.776	-106092.580	608.998	239109.727	-106092.529	608.960	-4.9	5.1	-3.8	8.0	64	19.01	362
18	66	239134.440	-106100.369	609.561	239134.409	-106100.312	609.520	-3.1	5.7	-4.1	7.6	58	32.49	1056
19	67	239139.389	-106107.308	609.324	239139.350	-106107.258	609.283	-3.9	5.0	-4.1	7.6	57	35.95	1292
20	68	239085.802	-106091.614	609.638	239085.743	-106091.598	609.624	-5.9	1.6	-1.4	6.2	39	25.99	675
21	69	239115.089	-106101.881	610.201	239115.054	-106101.822	610.160	-3.5	5.9	-4.1	8.0	64	14.41	208
22	70	239122.455	-106114.652	609.052	239122.423	-106114.589	609.016	-3.2	6.3	-3.6	7.9	63	19.30	373
23	71	239112.110	-106127.976	608.803	239112.091	-106127.895	608.784	-1.9	8.1	-1.9	8.5	73	19.39	376
24	72	239104.759	-106118.222	608.557	239104.745	-106118.167	608.534	-1.4	5.5	-2.3	6.1	38	7.75	60
25	73	239096.176	-106108.631	608.298	239096.155	-106108.588	608.275	-2.1	4.3	-2.3	5.3	29	7.66	59
26	74	239093.308	-106115.799	609.492	239093.299	-106115.757	609.477	-0.9	4.2	-1.5	4.6	21	11.54	133
27	75	239092.675	-106130.321	609.256	239092.693	-106130.250	609.250	1.8	7.1	-0.6	7.3	54	22.58	510
28	76	239083.154	-106125.045	609.605	239083.188	-106125.003	609.607	3.4	4.2	0.2	5.4	29	25.05	627
29	77	239117.726	-106109.538	608.847	239117.691	-106109.484	608.810	-3.5	5.4	-3.7	7.4	55	14.17	201
30	78	239120.146	-106084.101	609.490	239120.104	-106084.03	609.453	-4.2	7.1	-3.7	9.0	82	31.21	974
											m =	8.3	Σ =	36620

Initial / current data

step	0.1
x0 (or current), m	239103.590
y0 (or current), m	-106110.560
t	100

GO