Trimble and PhaseOne Inpho UASMaster workflow case study

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Revision 1.0

Contents

1. Introduction

1.1. Trimble

Trimble integrates a wide range of positioning technologies including GPS, laser, optical and inertial technologies with application software, wireless communications, and services to provide complete commercial solutions. Its integrated solutions allow customers to collect, manage and analyze complex information faster and easier, making them more productive, efficient and profitable.

Trimble products are used in over 150 countries around the world. Employees in more than 35 countries, coupled with a highly capable network of dealers and distribution partners serve and support our customers.

By integrating sensors, field applications, real-time communications, field and back-office processing, modeling, and analytics, Trimble Geospatial solutions facilitate a high quality, productive workflow and data exchange to drive efficiency, productivity, safety and value in organizations of all sizes. The result is rich accurate data that can be transformed into the intelligence you – and your clients – require to make informed decisions.

1.2. PhaseOne Industrial

Phase One's medium format iXU-RS1000 series cameras, have earned a worldwide reputation and are used in small and medium size area mapping projects, corridor mapping, LiDAR mapping, urban mapping, 3D City modeling and oblique imagery capturing, constructions and infrastructure monitoring and inspection.

The 100MP cameras specifications include: pixel size of 4.6 µ, very high image capture rate -1 frame every 0.6 seconds, exposure time of up to 1/2500, a set of metric lenses with different focal lengths (50, 70, 90, 110, 150 mm). This provides an effective solution in many areas of aerial mapping, monitoring and object inspection.

Small form size (10x10x20cm including lenses) and extremely light weight (less than 2 kg) are significant advantages of the camera allowing an easy installation in every small and light aircraft, gyrocopters, medium size drones or UAVs. These physical attributes essentially increase the range of airborne vehicles utilized for mapping, and significantly reduces operational costs of mapping projects.

The main goal of this report is photogrammetric accuracy analysis and assessment of IXU-RS1000 camera.

2. Testing Procedure

The photogrammetric accuracy assessment was done according to an aerial survey camera testing procedure, which includes the following steps:

- Test field establishment
- Flight planning and flight execution
- Automatic image matching and aerial triangulation (AT)
- DSM and DTM production
- Orthophoto creation
- AT accuracy analysis with different GCP & ChP configuration
- Orthomosaic accuracy including cut-line accuracy
- Final conclusions

The following steps were executed in the project:

1. Test field preparation
   a. Planning – Dr. Yuri Raizman, PhaseOne.Industrial (http://industrial.phaseone.com/)
   b. Geodetic measurements – ARMIG Geodetic Engineering Ltd. (www.armig.co.il/english)
2. Test flight planning, flight execution and image preparation – Oodi Menaker, PhaseOne.Industrial
3. Photogrammetric processing (AT, DSM, Orthophoto, GCPs measurements) – Barbara Quedenfeldt, Team Leader Inpho Support - Imaging Division, Trimble Germany GmbH; (www.trimble.com/geospatial)
4. Accuracy analysis and report preparation – Barbara Quedenfeldt and Dr. Yuri Raizman

The following software was used for the project:

- iX Capture – original image processing and export to TIFF format
- Inpho UASMaster Version 9.0. - AT, DSM, Orthophoto

3. Test Field

3.1. Area

The test field is situated in the vicinity of Kfar-Vitkin, Israel. It covers 2.0 km form the West side to the East side of the village, and 1.2 km from the South-to the North side of the village. It is predominantly an urban area with low height of up to two-story buildings.

Figure 1: Test field

The area is characterized by visible manmade features and manholes, which were chosen to serve as signalized GCPs. All GCPs are located on the ground. The following manmade features and manholes were used mainly as GCPs:

There are 53 GCPs in the test field

3.2. Geodetic Measurements

Before performing the field measurements, all GCPs were identified and marked on Phase One's images of the area. The geodetic observations were made according to static GPS survey procedure with one reference station 903AGR. The reference station was established at the high and open area in the north part of the test field. The reference station was measured against CSAR permanent GPS station by two independent 1-hour long observation sessions. Each GCP was measured by two independent half-hour long observation sessions.

The following accuracies of the GCPs were received after processing all the observations:

	RMSxy (cm)	RMSz (cm)
CSAR	± 0.3	± 0.5
903AGR vs CSAR	± 0.1	± 0.1
GCPs internal between observations	± 0.7	± 1.2
GCPs absolute	± 0.8	± 1.3

4. Flight Planning

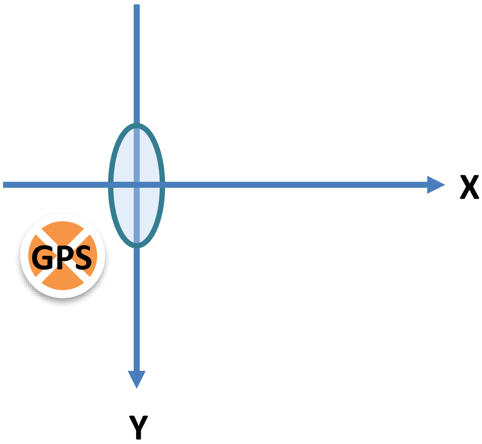
4.1. Aerial Camera

An iXU-RS1000 aerial camera with a focal length of 90 mm was used for the test. The main parameters of the camera are as follows:

Camera Specifications	
Lens type	Rodenstock
Focal length (mm)	90
FOV (across flight, deg)	33.0
FOV (along flight, deg)	25.1
Aperture	f/5.6
Exposure principle [1]	Leaf shutter
Exposure (sec)	1/2500 to 1/125
Image capture rate (sec)	0.6
Light Sensitivity (ISO)	50-6400
Dynamic Range (db)	>84
Sensor Specifications	
Sensor type	CMOS
Pixel size (µm)	4.6
Array (pix)	11,608 x 8,708
Array volume (MP)	100
Analog-to-digital-conversion (bit)	14
Frame / Image Specifications	
Frame geometry	Central projection
Typical image size (MB) for TIFF	300
Image format	PhaseOne RAW, Undistorted TIFF, JPEG
Frame Coverage	
Frame width for 10 cm GSD (m)	1,161
Frame height for 10 cm GSD (m)	871
Frame area for 10 cm GSD (sq.km)	1.01

4.2. Aircraft Installation

A Cessna 172 aircraft was used for the flight. The camera was installed at the rear part of the plane with the following parameters of lever arm (distance between GPS antenna and the exit pupil of the camera):



dX (cm)	-15.4
dY (cm)	10.1
dZ (cm)	0.99

4.3. Aerial Survey Parameters

The flight was planned and executed with the following aerial survey parameters:

- Flight altitude (above ground) - 2,500 feet / 760 м
- GSD – 4 cm
- Distance between flight lines – 230 m
- Distance between projection centers at 60% forward overlap – 135 m
- Side overlap – 49%
- Forward overlap – 80%
- Frame size – 450m x 340m
- Orthophoto angle - 17°
- Building lean – 15%
- Ground speed – 100 knot
- Strips: SN – 9; WE – 2;

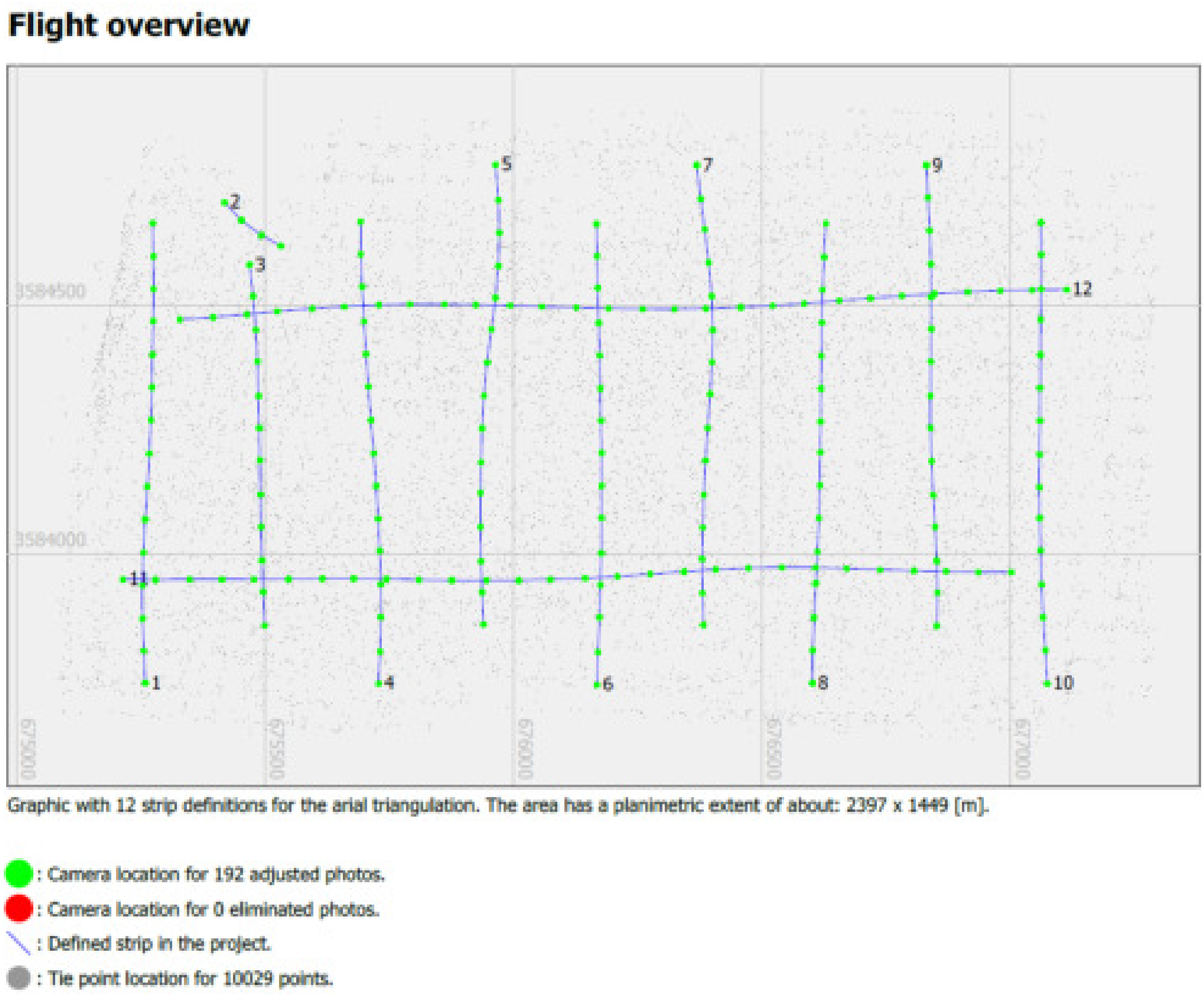


Figure 2: Test field with flight lines

5. Inpho UASMaster - Aerial Triangulation

There were 192 images in the project and 10,029 tie points were automatically created. The image coordinates of all 63 GCPs were manually measured using the **Inpho UASMaster**. Bundle-block adjustment was performed for self-calibration and exterior orientation of the block with different number and configuration of used GCPs. Photogrammetric accuracy of the block is estimated by residuals on tie points. Geodetic accuracy of the block is estimated by residuals on GCPs, which were not included into the adjustment – Check Points (ChP).

This project was processed using different processing options. Main difference of these processes is the usage of GNSS (retrieved from the EXIF information) as well as the number of GCPs being used for calibration and adjustment.

Project A: Software used: **UASMaster** with project type **Area Mapping**. To be able to use the type Area Mapping, GNSS information from the EXIF header had to be used. This included lat/lon/height values. As GCPs all measureable/identifiable GCPs were used during tie points extraction and camera calibration. For calibration, the GNSS information from the EXIF was used with standard deviation of 10 m. Based on this orientation, a point cloud in LAS format was generated as well.

Projects B: Same as Project A, but as difference only a subset of 5 GCPs for the processing (camera calibration) was used. All remaining points were used as Check Points. Tie points were reused from the project A.

Process C: Same as Project B, but as difference a subset of 9 GCPs for the processing (camera calibration) was used. All remaining points were used as Check Points. Tie points were reused from the project A.

Process C1: Same as project C, but during calibration, the GNSS usage was switched off completely.

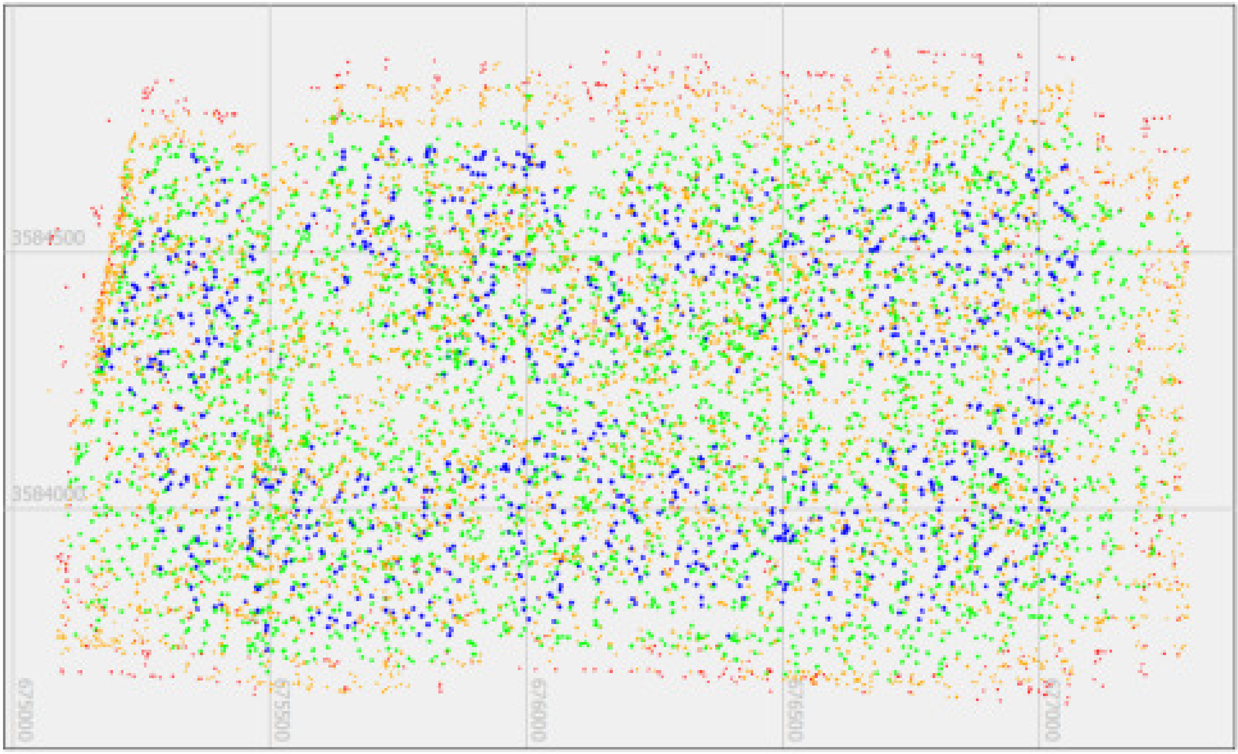
Process D: For the processing, the **UASMaster** project type **Close Range** was used. The difference to the Area Mapping processing type is that no EXIF information was used as input observation. Input data for tie points extraction used was therefore only images and GCPs. No EXIF information/GNSS information was used. Camera positions were defined based only on image analysis. After tie points matching and calibration, the GCP measurements were imported, so exactly the same GCPs measurements compared to the Area Mapping type project were used. For this test, all available GCPs were used as full GCPs. With this information an additional camera calibration was performed. During the calibration, the focal length was calibrated as well. However, this is based on the availability of one flying height and not necessarily representative for any other projects where the camera might be reused.
The following presents a tie points distribution per image:

Frequency of image point observations in the photos

Fold	Number of image points	%
2	815	8.08
3	1868	18.52
4	2489	24.68
5	1103	10.93
6	843	8.36
7	549	5.44
8	429	4.25
9	406	4.02
10	377	3.74
11	339	3.36
12	341	3.38
13	242	2.40
14	149	1.48
15	81	0.80
16	37	0.37
17	17	0.17
18	1	0.01
19	1	0.01

Appearance of 10087 image points from the statistic file. The table contains all image observations of the points.

Tie point distribution



Tie point distribution of 10029 points in the project. The point size and colour reflects the number of images containing the point. The area has a planimetric extent of about: 2397 x 1449 [m] and a height range of about: 9 - 63 [m].

- : Point found in (0-2) images.
- : Point found in (3-4) images.
- : Point found in (5-10) images.
- : Point found in (>10) images.

6. AT accuracy analysis for different GCP & ChP configurations

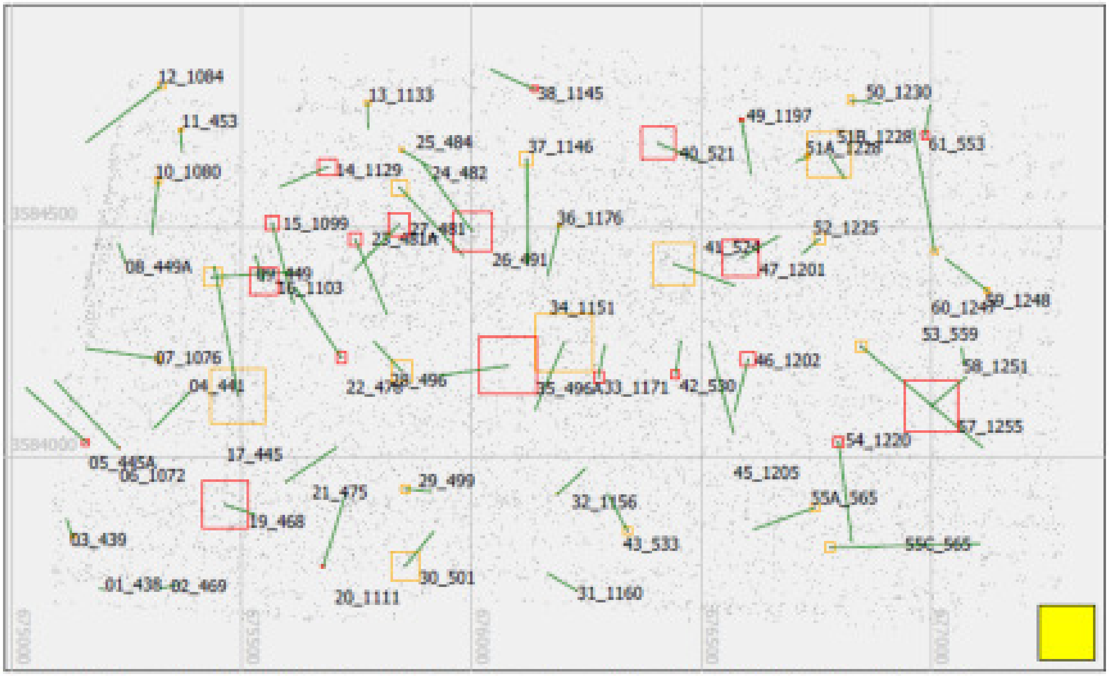
Four different GCP and ChP configurations and different options of GNSS data were selected for testing geodetic accuracy of the block.

Project A and D: 58 GCPs with use of approximate GNSS data from EXIF (Project A, UASMaster in the Area Mapping mode) and without use of GNSS data (Project D, UASMaster in the Close Range mode)

All GCPs were used in the block adjustment.

	Project A - 58 GCP			Project D – 58 GCP		
	dX (cm)	dY (cm)	dZ (cm)	dX (cm)	dY (cm)	dZ (cm)
MIN	-0.021	-0.029	-0.016	-0.021	-0.025	-0.006
MAX	0.041	0.036	0.016	0.032	0.048	0.006
Mean	0.000	0.000	0.000	0.000	0.000	0.000
STDEV	0.012	0.014	0.006	0.012	0.015	0.002
RMS	**0.012**	**0.014**	**0.006**	**0.012**	**0.015**	**0.002**

Ground control point residuals



Graphic with 58 ground control points from the project. The points are shown with its residuals for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m]. Residual is defined as: residual = given - adjusted.

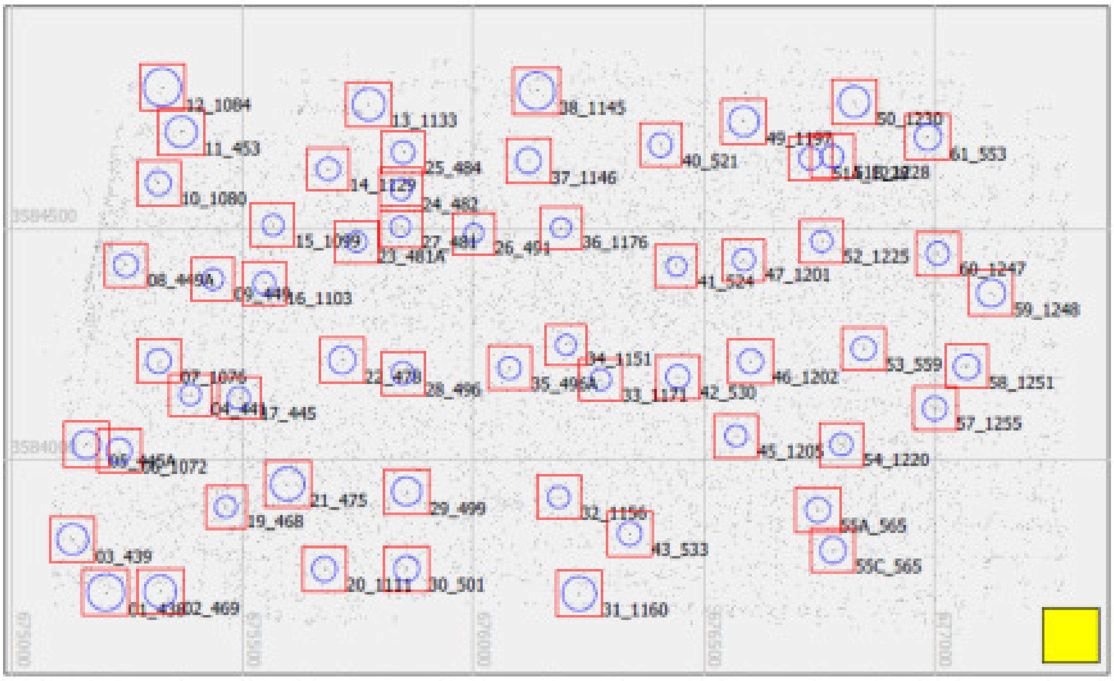
: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.

: Residual XY (58) for ground control points (min=0.0017, avg=0.0160, max=0.0435 [m]).

: Residual Z (pos.:24/neg.:34) for ground control points (min=-0.0157, avg=0.0001, max=0.0158 [m]).

: Tie point location for 10029 points.

Ground control point standard deviations



Graphic with 58 ground control points from the project. The points are shown with its standard deviations for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.

: Standard deviation XY for 58 ground control points (min=0.0073, avg=0.0097, max=0.0145 [m]).

: Standard deviation Z for 58 ground control points (min=0.0111, avg=0.0120, max=0.0127 [m]).

: Tie point location for 10029 points.

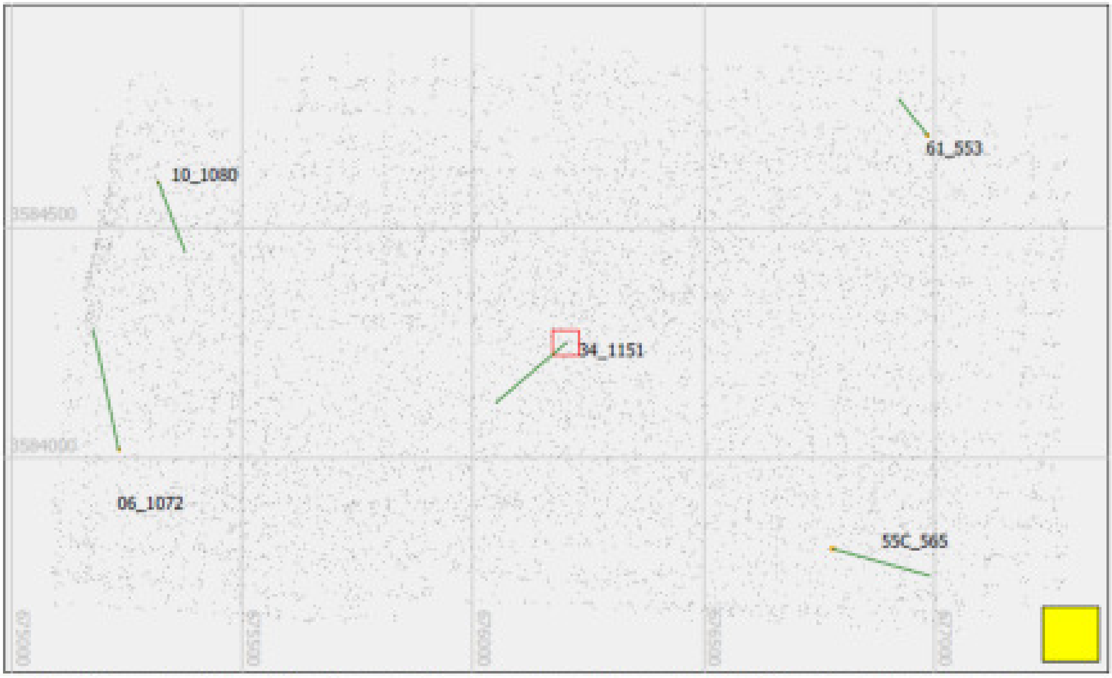
Project B: 5 GCPs and 53 ChP with use of approximate GNSS data from EXIF

The following results were obtained:

	5 GCP			53 Check Points			
	dX (cm)	dY (cm)	dZ (cm)	dX (cm)	dY (cm)	dXY (cm)	dZ (cm)
MIN	-1.9	-1.9	-0.1	-5.3	-4.7	7.1	-11.7
MAX	2.7	3.3	0.7	3.9	6.0	7.1	20.4
Mean	0.0	0.0	0.1	-0.7	0.4	0.8	4.9
STDEV	1.6	1.9	0.3	1.9	2.5	3.1	6.9
RMS	**1.6**	**1.9**	**0.3**	**2.0**	**2.5**	**3.21**	**8.42**

With 5 GCPs and for 53 Check Points, the RMSxy was ± 3.21 cm (0.8 pix) while the RMSz = ± 8.42 cm (2.1 pix) on Check Points.

Ground control point residuals



Graphic with 5 ground control points from the project. The points are shown with its residuals for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m]. Residual is defined as: residual = given - adjusted.

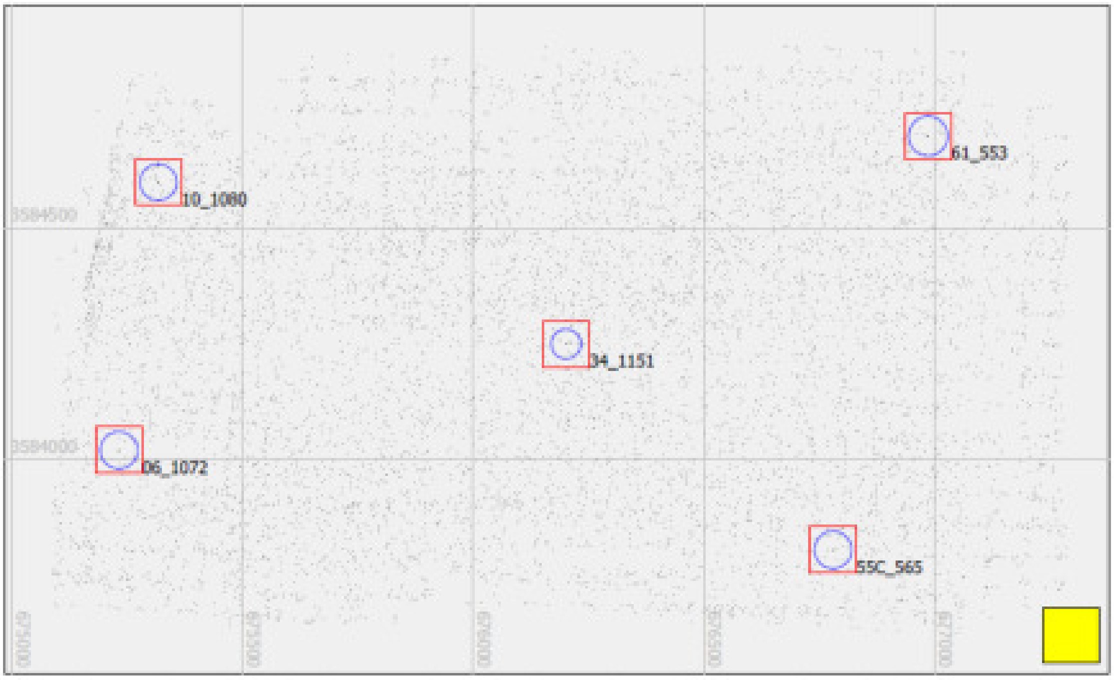
: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.

: Residual XY (5) for ground control points (min=0.0127, avg=0.0238, max=0.0334 [m]).

: Residual Z (pos.:1/neg.:4) for ground control points (min=-0.0013, avg=0.0008, max=0.0071 [m]).

: Tie point location for 10081 points.

Ground control point standard deviations



Graphic with 5 ground control points from the project. The points are shown with its standard deviations for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.

: Standard deviation XY for 5 ground control points (min=0.0115, avg=0.0139, max=0.0152 [m]).

: Standard deviation Z for 5 ground control points (min=0.0126, avg=0.0126, max=0.0127 [m]).

: Tie point location for 10081 points.

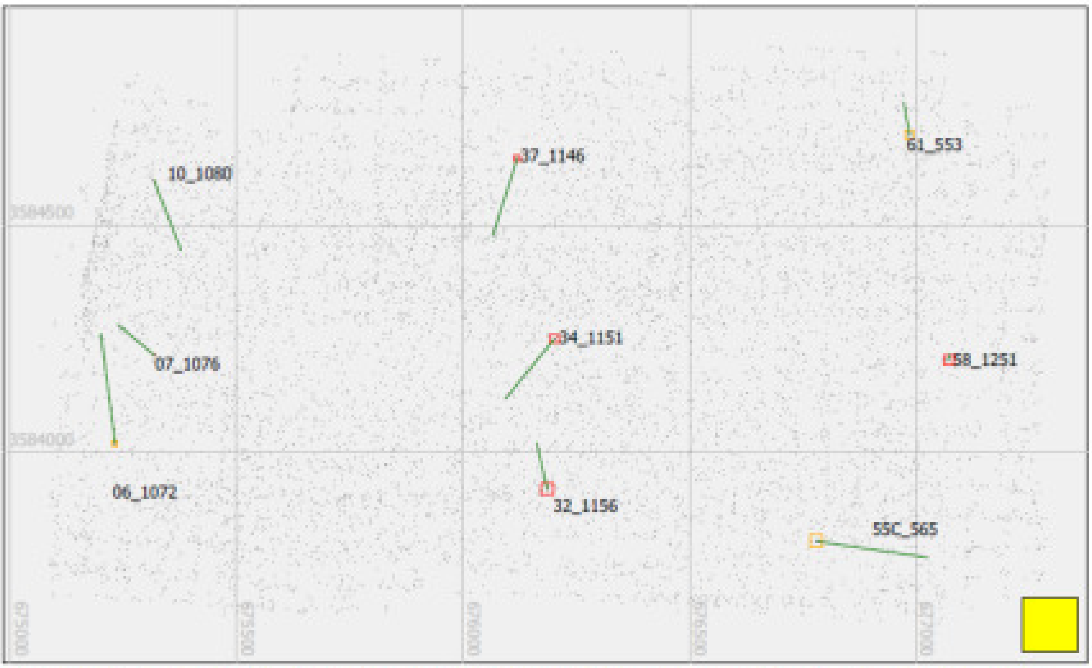
Project C: 9 GCPs and 49 ChP with use of approximate GNSS from EXIF

The following results were obtained:

	9 GCP			49 Check Points			
	dX (cm)	dY (cm)	dZ (cm)	dX (cm)	dY (cm)	dXY (cm)	dZ (cm)
MIN	-1.4	-2.2	-0.3	-4.5	-4.4	6.3	-13.3
MAX	3.1	3.0	0.3	4.4	5.6	7.1	18.1
Mean	0.0	0.0	0.0	-0.1	0.4	0.4	3.3
STDEV	1.2	1.6	0.2	1.9	2.3	3.0	7.0
RMS	**1.2**	**1.6**	**0.2**	**1.9**	**2.3**	**3.01**	**7.71**

With 9 GCPs and for 49 Check Points, the RMSxy was ± 3.01 cm (0.8 pix) while the RMSz was ± 7.71 cm (1.9 pix) on Check Points.

Ground control point residuals



Graphic with 9 ground control points from the project. The points are shown with its residuals for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m]. Residual is defined as: residual = given - adjusted.

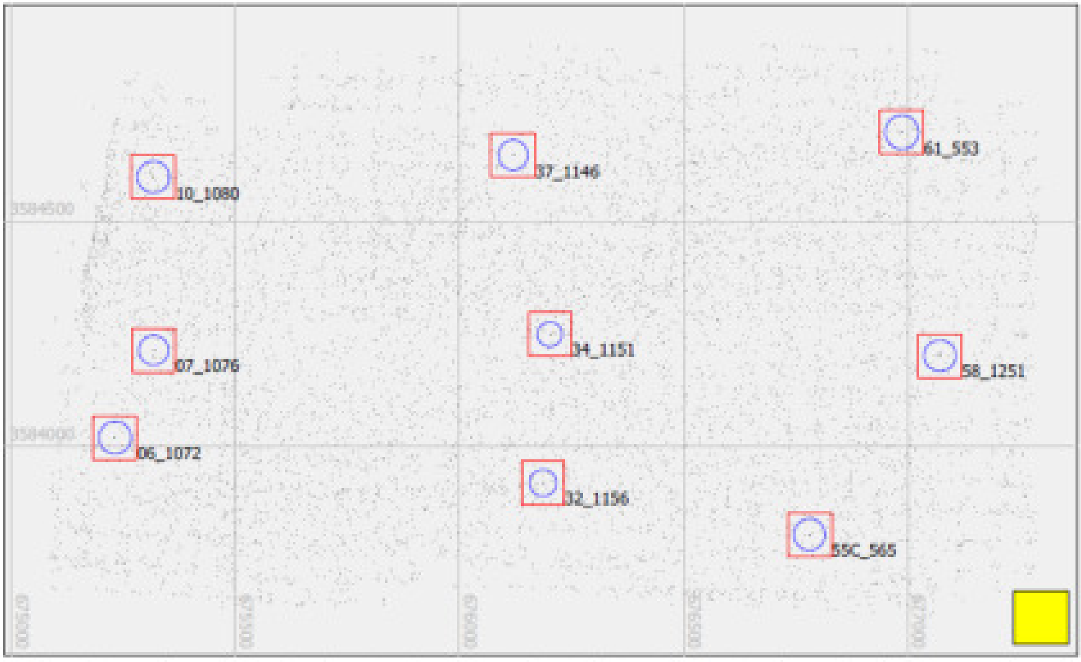
: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.

: Residual XY (9) for ground control points (min=0.0017, avg=0.0182, max=0.0314 [m]).

: Residual Z (pos.:5/neg.:4) for ground control points (min=-0.0033, avg=0.0004, max=0.0033 [m]).

: Tie point location for 10080 points.

Ground control point standard deviations



Graphic with 9 ground control points from the project. The points are shown with its standard deviations for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.

: Standard deviation XY for 9 ground control points (min=0.0098, avg=0.0120, max=0.0134 [m]).

: Standard deviation Z for 9 ground control points (min=0.0121, avg=0.0123, max=0.0125 [m]).

: Tie point location for 10080 points.

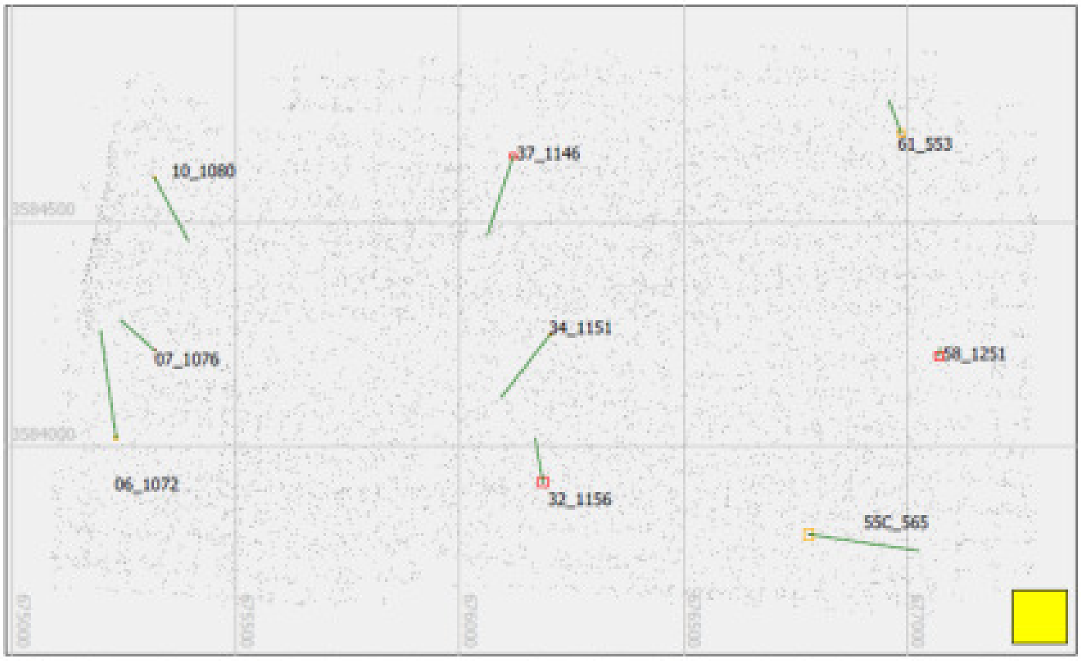
Project C1: 9 GCPs and 49 ChP without use of approximate GNSS from EXIF

The following results were obtained:

	9GCP			49 Check Points			
	dX (cm)	dY (cm)	dZ (cm)	dX (cm)	dY (cm)	dXY (cm)	dZ (cm)
MIN	-1.4	-2.2	-0.3	-4.6	-4.1	6.1	-11.9
MAX	3.1	3.0	0.3	4.5	5.3	7.0	17.1
Mean	0.0	0.0	0.0	-0.1	0.4	0.4	3.0
STDEV	1.3	1.6	0.2	1.9	2.3	3.0	6.7
RMS	**1.3**	**1.6**	**0.2**	**1.9**	**2.3**	**2.99**	**7.38**

With 9 GCPs and for 49 Check Points, the RMSxy = ± 2.99 cm (0.7 pix) and RMSz = ± 7.38 cm (1.8 pix) were obtained.

Ground control point residuals



Graphic with 9 ground control points from the project. The points are shown with its residuals for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m]. Residual is defined as: residual = given - adjusted.

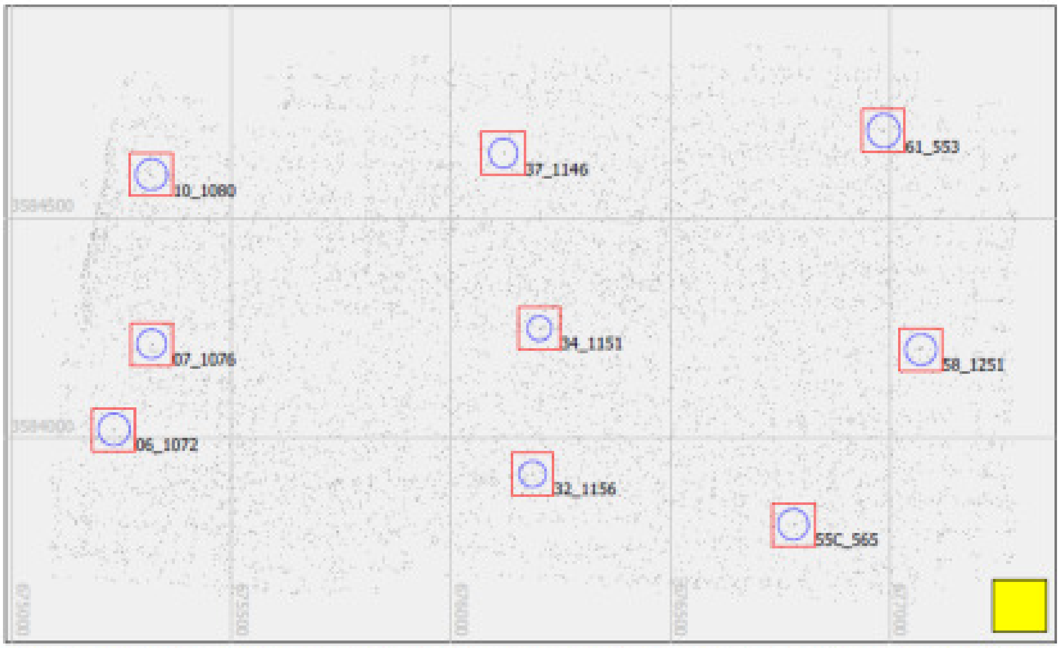
: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.

: Residual XY (9) for ground control points (min=0.0024, avg=0.0183, max=0.0313 [m]).

: Residual Z (pos.:4/neg.:5) for ground control points (min=-0.0029, avg=-0.0000, max=0.0027 [m]).

: Tie point location for 10079 points.

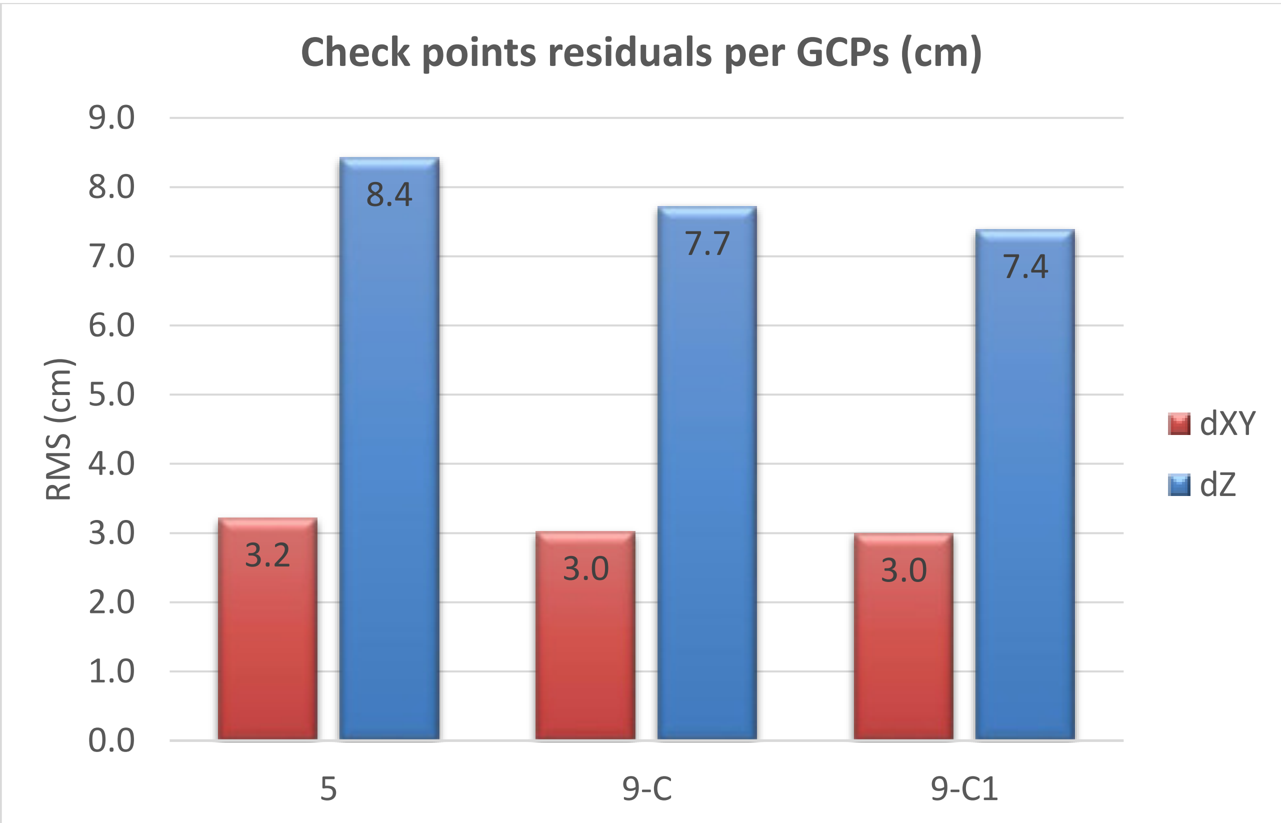
Ground control point standard deviations



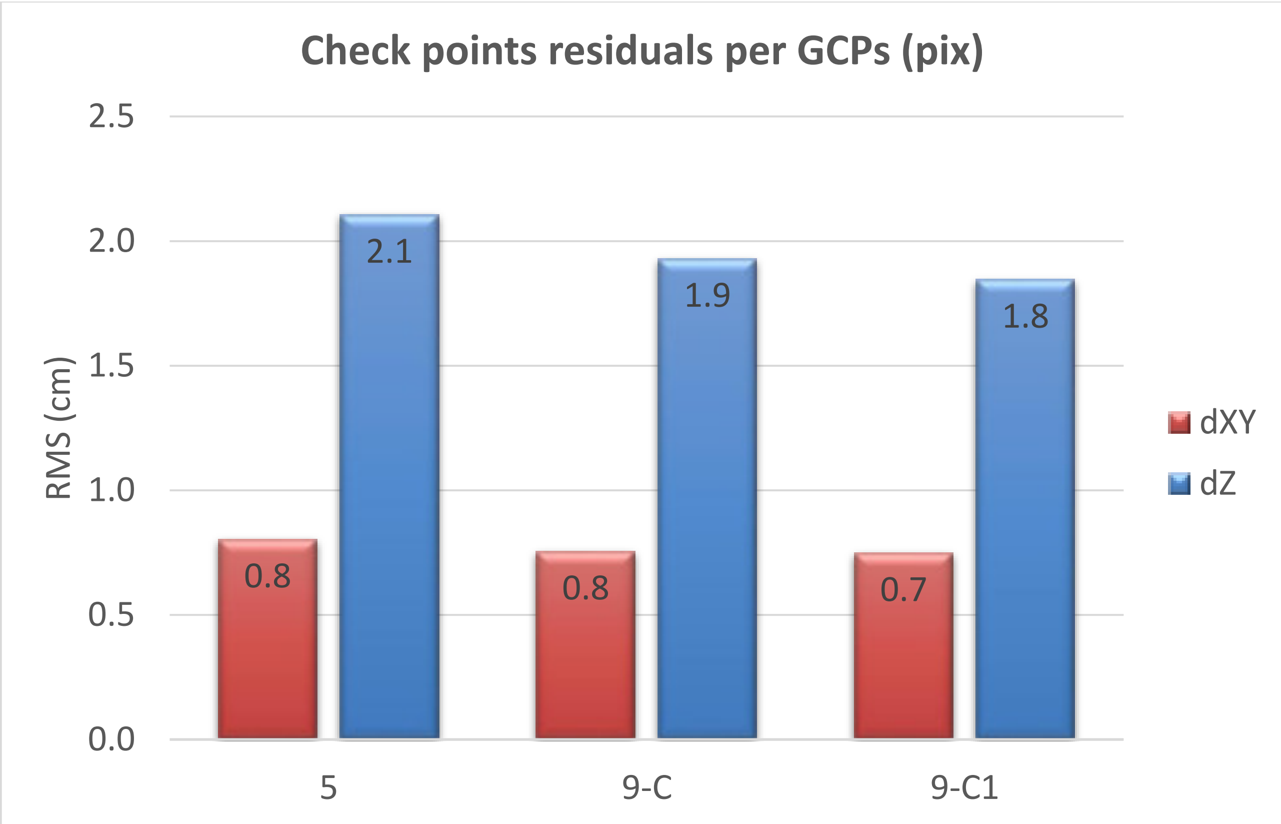
Graphic with 9 ground control points from the project. The points are shown with its standard deviations for XYZ from the adjustment. The area has a planimetric extent of about: 2397 x 1449 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.015 [m] in the object.
: Standard deviation XY for 9 ground control points (min=0.0098, avg=0.0120, max=0.0134 [m]).
: Standard deviation Z for 9 ground control points (min=0.0121, avg=0.0123, max=0.0125 [m]).
: Tie point location for 10079 points.

The chart below presents the results of the accuracy analysis:



Planimetric accuracy of the block on Check Points is always at the level of 0.7 - 0.8 pixel independently of the number and configuration of GCPs used for adjustment and exterior orientation of the block. Altimetric accuracy of the block on Check Points starts from 8.4 cm (2.1 pix) with 5 GCPs, and reaches to 7.4 cm (1.8 pix) with 9 GCPs. This altimetric accuracy is considered as high accuracy and even may be improved by using high accuracy GPS data.



7. Conclusions

The goal of the report was to check the INPHO UASMaster software workflow processing PhaseOne iXU RS1000 images for mapping projects. The following results were obtained:

1. INPHO UASMaster software can process PhaseOne images as a standard procedure.
2. INPHO UASMaster software with PhaseOne images leads to mapping products of high accuracy.
3. Phase One iXU-RS1000 is a metric camera with stable and clearly definable interior orientation parameters
4. Images captured by the camera are of a high geometric and radiometric quality ensuring the use of the camera in high accuracy mapping projects, including stereocompilation
5. Planimetric accuracy of 3 cm (0.7 pixel) has been reached with only 5 GCPs in the block.
6. Altimetric accuracy corresponded to 8.4 cm (2.1 pix) with 5 GCPs and it may be improved by using high accuracy GNSS data.