Phase One iXU-RS1000 Accuracy Assessment Report

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1. Introduction

The Phase One medium format cameras of the series iXU-RS1000 are well known worldwide and very popular for 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 with pixel size of 4.6 μ, very high image capture rate -1 frame every 0.6 seconds and exposure time of up to 1/2500, a set of metric lenses with different focal lengths (50, 70, 90, 110, 150 mm), provide a very effective solution in many areas of aerial mapping, monitoring and object inspection.

A very small form size (10x10x20cm including lenses) and a very light weight (less than 2 kg) are also significant advantages of the camera – it may be installed easily in every small and light aircrafts, gyrocopters, medium size drones or UAVs that essentially increase a range of airborne vehicles utilized for mapping and significantly reduces operational costs of mapping projects.

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

2. Testing procedure

The photogrammetric accuracy assessment was done according to widely accepted aerial survey camera testing procedure, including the following steps:

- Test field establishment
- Flight planning and flight execution
- Automatic image matching and aerial triangulation (AT)
- Flight camera calibration based on AT
- AT accuracy analysis with different GCP & ChP configuration
- Stereoscopic measurements of GCP & ChP
- Final conclusions

The main steps of the project were executed by several geospatial, geodetic and photogrammetric companies, which are most experienced in the relevant fields:

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. Image matching (automatic tie points measurements), bundle block adjustment, GCP & ChP measurements – Dr. Ziv Shragai from Simplex Mapping Solutions Ltd. (www.simplex-mapping.com) and Dr. Erwin Kruck from GIP, Dr. Kruck & Co. GbR (http://bingo-atm.de/)

4. Stereoscopic GCP&ChP measurements – Mapping Technology Ltd.

5. Accuracy analysis and report preparation – Dr. Yuri Raizman, PhaseOne.Industrial

The following software was used for the project:

- iX Capture – original image processing and export to TIFF format
- Agisoft Photoscan Pro – automatic image matching and GCP & ChP measurements
- Bingo – aerial triangulation, bundle block adjustment, camera calibration, and accuracy assessment
- AtlasKLT – stereoscopic measurements of GCP & ChP

3. Test Field

3.1. Area

The test field is situated in the area of a village Kfar-Vitkin, Israel. It extends on 2.0 km in the West-East direction and 1.2 km in the South-North direction. It is mostly an urban area with low height one-two-story buildings.

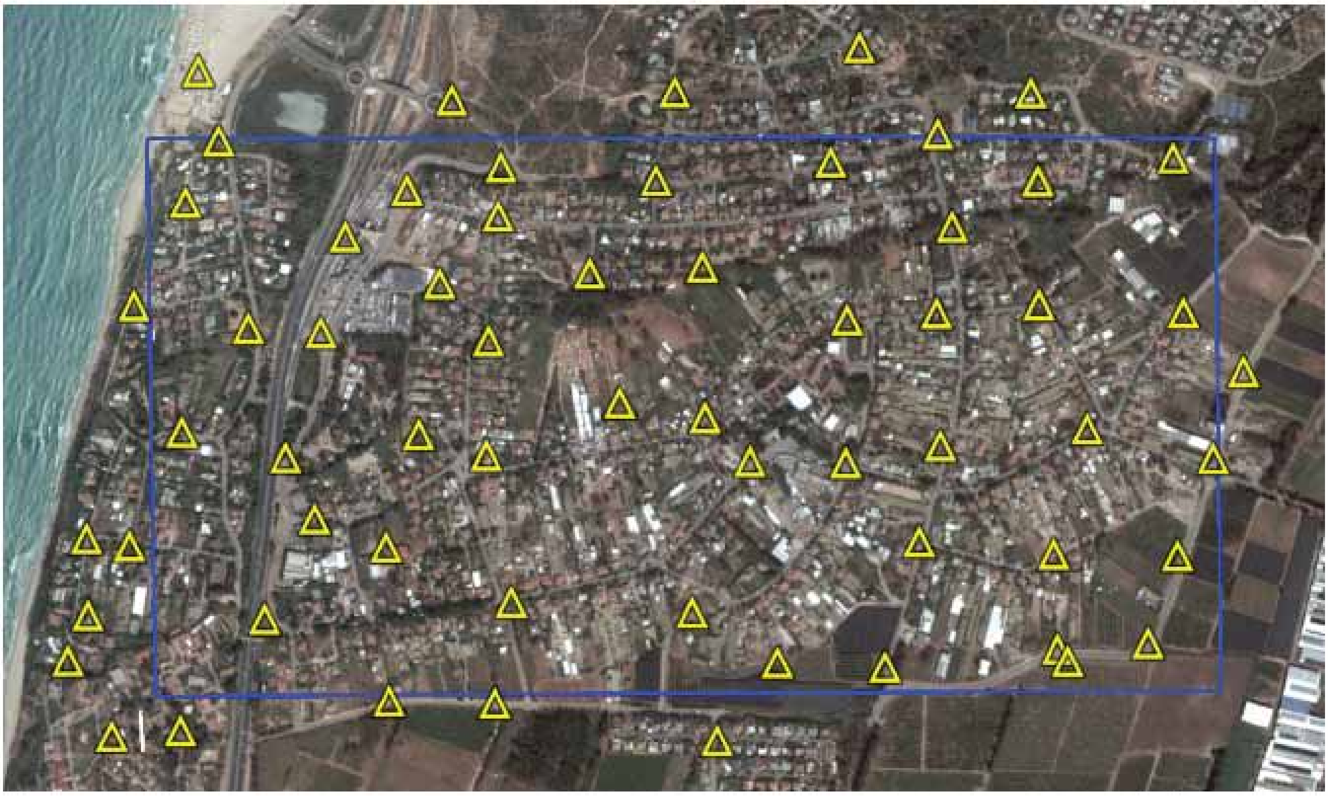


Figure 1: Test field

The area characterized by existence of many permanent, visible from all sides and well-defined manmade features, which were chosen to serve as signalized GCPs. All GCPs are located on the ground. The following manmade features were mainly used as GCPs:

There are 53 GCPs in the test field.

3.2. Geodetic measurements

Before making the field measurements, all GCPs were identified and marked on the Phase One 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. Every 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

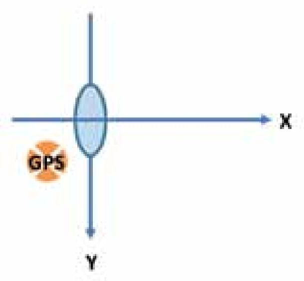
4. Flight Planning
4.1. Aerial camera

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

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

Aircraft Cessna 172 was used for the flight. The camera was installed in 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
- GSD – 4 cm
- Distance between flight lines – 230 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. Image matching and aerial triangulation

The image matching was performed with Agisoft Photoscan Pro software. There were 202 images in the matching and 6,434 tie points (39,335 x,y image measurements) were identified during the matching. The image coordinates of all GCPs were manually measured in Photoscan Pro.

After the matching, all tie points and GCPs image coordinates were provided to Bingo software for further processing.

The Bingo software was used for bundle-block adjustment with additional parameters 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 or by sigma 0. Geodetic accuracy of the block is estimated by residuals on GCPs, which are not participated in the adjustment – Check Points (ChP).

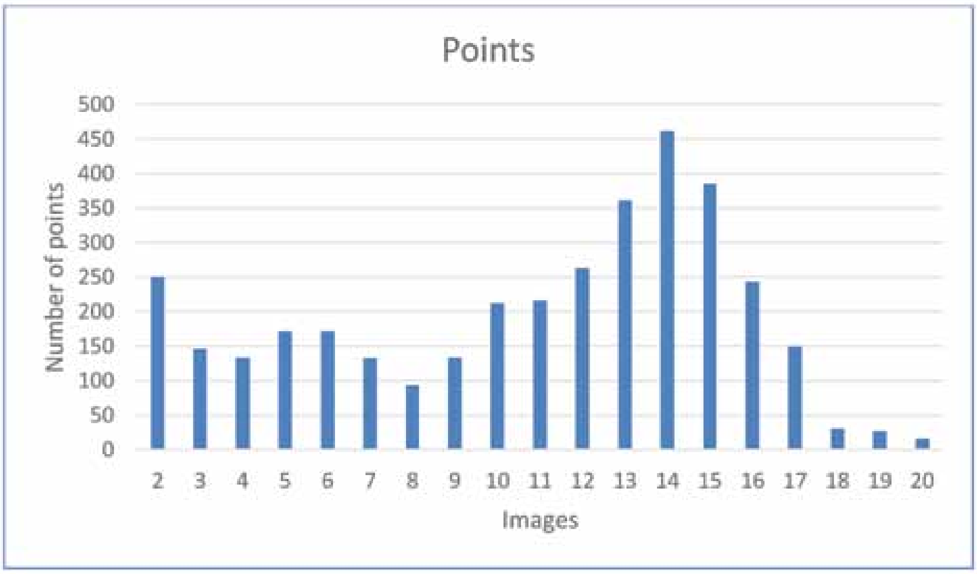
There were five runs of Bingo for different purposes:

1. Tie point and all 53 GCP adjustment with additional parameters 61, 62 for camera calibration
2. Tie point and all 53 GCP adjustment with additional parameters 17,18,19,39,61,62 and 65 for camera calibration
3. Tie points, 5 GCP and 48 ChP for the block geodetic accuracy estimation
4. Tie points, 9 GCP and 44 ChP for the block geodetic accuracy estimation
5. Tie points, 15 GCP and 38 ChP for the block geodetic accuracy estimation

Common parameters of the block for the above Bingo runs are as following:

- Number of images – 202
- Number of used tie points – 3600
- Number of skipped tie points - 2835
- Mean number of points per image – 222
- Number of measured GCPs - 53

The following graph presents a tie points distribution per images:



Images in the middle of the block with multiple overlaps have more identified tie points than images along the perimeter of the block with only a few overlapping images.

6. Camera self-calibration analysis

The self-calibration procedure is a simultaneous bundle adjustment of all images of the block with many tie points and many GCPs participating in the adjustment. During the self-calibration, the camera interior orientation parameters (camera model), F, xo, yo, k1, k2, p1, p2, p3 are calculated. The accuracy of these parameters depends on many factors – number and size of image overlaps, number and accuracy of identified tie points, number and accuracy of GCPs, existence and accuracy of GPS during the flight and some more.

As mentioned above, 202 images with an average 202 tie points per image and 53 GCPs participated in the adjustment. Only approximate GPS data was used for the adjustment.

The camera self-calibration procedure was processed twice with different sets of additional parameters. The first set included additional parameters 61 and 62, which correspond to K1 and K2 radial distortion coefficients in standard Brown-Conrady distortion model.

The second set included additional parameters 17, 18, 19, 39, 61, 62 and 65 and was provided and tested by Dr. Erwin Kruck, the developer of Bingo software.

After the adjustment of all images, the following results obtained:

	Tie points residuals					57 GCP		
	Image		Ground			Ground		
	dx (µm)	dy (µm)	dX (cm)	dY (cm)	dZ (cm)	dX (cm)	dY (cm)	dZ (cm)
MIN	-7.1	-8.1	0.3	0.3	0.5	-3.0	-3.1	-0.3
MAX	7.2	9.3	5.7	3.5	16.6	1.2	1.7	0.3
Mean	0.0	0.0	0.7	0.6	3.2	0.0	0.0	0.0
STDEV	1.7	1.6	0.4	0.3	2.1	0.6	0.7	0.1
RMS	1.7	1.6	0.8	0.7	3.8	0.6	0.7	0.1
Sigma 0	1.79 / 1.83 µm (depending on a number of additional parameters) 0.4 of pixel size							

The results clearly present a very high photogrammetric accuracy of the block. The RMS of tie point s is just 1.7 µm in the image plane (0.3 of pixel). The RMS of tie points on the ground is 0.8 cm in position (0.2 of pixel size on the ground) and 3.8 cm in height that is 0.8 of pixel size on the ground.

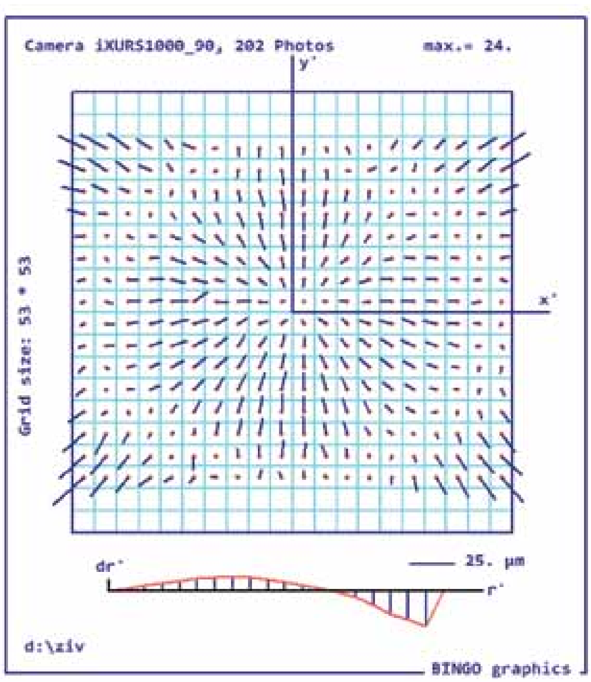
The relatively large difference in position and height accuracy may be explained by two factors: low accuracy of GPS during the flight and long focal length (90 mm) of the camera that influence the height accuracy.

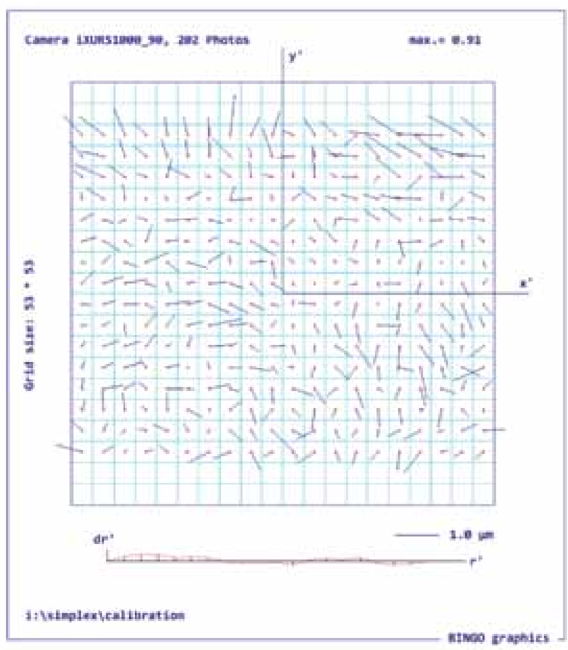
After the adjustment, the following main camera parameters were calculated:

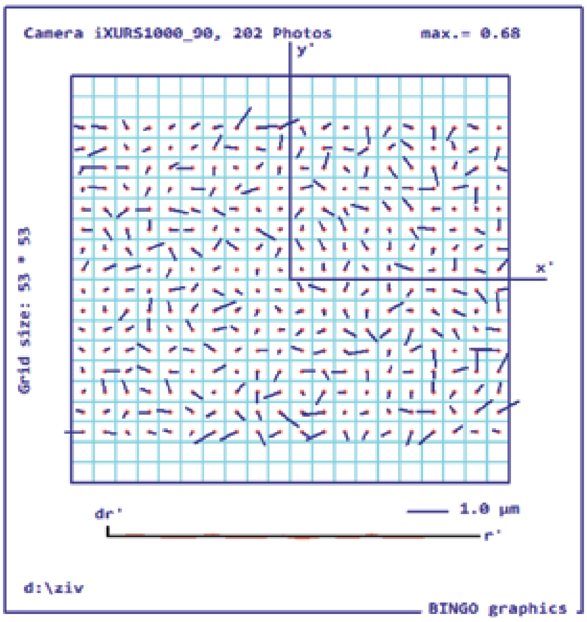
	F (mm)	Xp (mm)	Yp (mm)
	89.5447	0.0244	0.0149
RMS (µm)	10.1	1.5	1.5
RMS (pix)	2.20	0.33	0.33

The low accuracy of the focal length calculation (10.1 µm) may be explained by the low accuracy of GPS data already mentioned above.

During the self-calibration the camera model distortion was also calculated. The left picture below presents a clearly visible symmetrical radial distortion model of the camera with a maximal distortion of 24 µm before fixing the image.







The right image presents the same image after its fixing with 61, 62 additional parameters describing a simple symmetrical radial distortion model (corresponds to K1 and K2 coefficients). Maximal residual here is 0.91 µm, which is just 0.2 of pixel (4.6 µm).

The third picture from the left presents the same camera after implementing the following additional parameters 17,18,19,39,61,62,65, describing more complicated distortion model. In this case, the maximal residual equals to 0.86 µm.

As a conclusion, should be explicitly stated that the distortion model of the camera iXU-RS1000 with 90 mm focal length fully corresponds to a standard Brown-Conrady distortion model and images captured with the camera may be easily transformed to undistorted model with a maximal residual less than 1 µm.

7. Accuracy analysis for different GCP & ChP configuration

Several different GCP and ChP configuration were chosen for testing geodetic accuracy of the block.

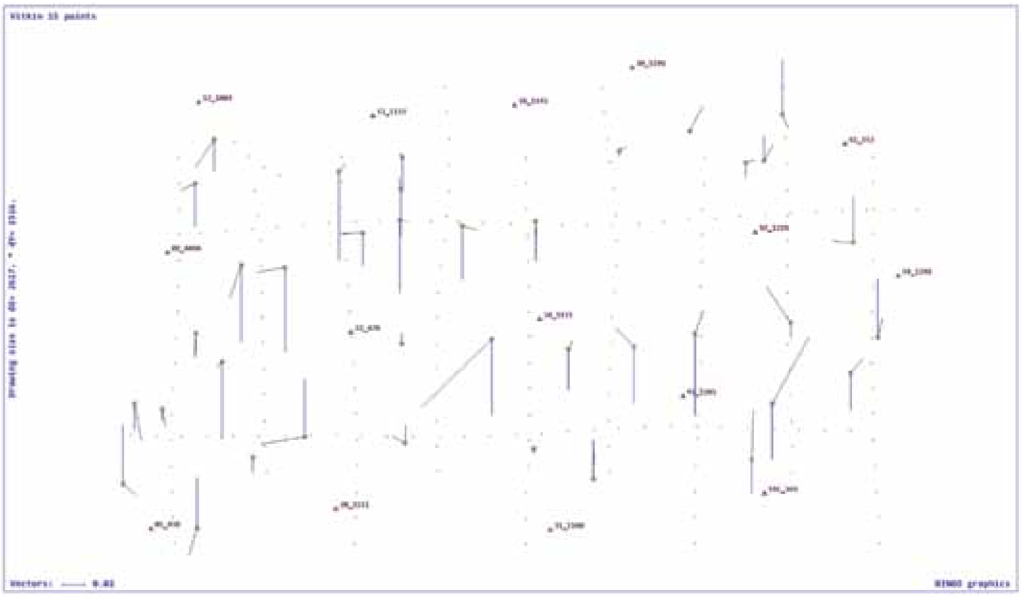
One of them is based on 15 GCP and 38 ChP:

The following results were obtained for this configuration:

	15GCP			38 Check Points			
	dX (cm)	**dY (cm)**	**dZ (cm)**	**dX (cm)**	**dY (cm)**	**dXY (cm)**	**dZ (cm)**
MIN	-0.8	-1.2	-0.2	-6.3	-6.2	8.8	-8.1
MAX	0.6	1.8	0.2	3.3	5.9	6.8	5.3
Mean	0.0	0.0	0.0	-0.3	0.1	0.3	-1.8
STDEV	0.4	0.6	0.1	1.6	2.1	2.7	4.0
RMS	0.4	0.6	0.1	1.7	2.1	2.7	4.4

With 15 GCP and for 38 Check Points the RMSxy = ± 2.7 cm (0.7 pix) and RMSz = ± 4.4 cm (1.1 pix) were obtained.

The following chart is a graphical representation of the residuals on Check Points:



The red vectors represent XY residuals and the blue one – Z residuals. There is no visible systematic errors in the block.

The planimetric accuracy of the block on Check Points is always at the level of 0.7 pixel independently on the number and configuration of GCPs used for adjustment and exterior orientation of the block.

The altimetric accuracy of the block on Check Points varies from 1.0 to 1.5 pix depending on the number of GCPs. This altimetric accuracy is considered as high accuracy and even may be improved by use of high accuracy GPS data.

8. Accuracy analysis from stereoscopic measurements

The aim of the stereoscopic test is to check a potential accuracy of stereoscopic measurements on images captured by iXU-RS1000 camera with focal length of 90 mm and to test a possible existence of the vertical parallax residuals after relative orientation .

The theoretical accuracy of stereoscopic measurements may be calculated as flowing:

$Mxy = H/F*mxy$; $Mz = H/b*mp$

Where:

Mxy – theoretical planimetric accuracy of stereoscopic measurement on the ground,

Mz – theoretical altimetric accuracy of

stereoscopic measurement on the ground,

mxy – accuracy of x,y measurement on the image plane,

mp – accuracy of parallax measurement on the image plane.

With the assumption, that mxy=mp=0.3 pix, for camera with F=90 mm and forward overlap of 60% the theoretical planimetric accuracy will be 0.3 pix and the altimetric – 1.7 pix.

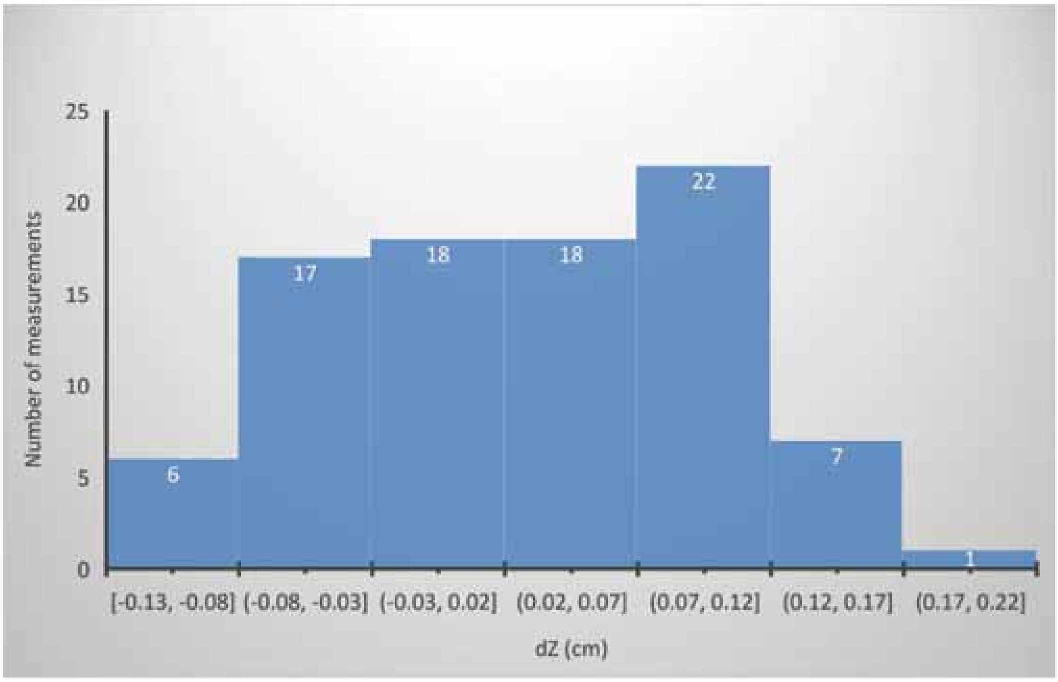
Mapping Technology Ltd. executed stereoscopic measurements. For the analysis, 56 GCPs on 91 stereopairs were measured. Stereopairs with 60% forward overlap were mainly selected. Several measurements were done with stereopairs formed with images from adjacent strips with using side overlap for stereoscopy. Every point was measured twice on the same stereopair. The Atlas KLT software was used for the stereoscopic measurements.

Exterior orientation parameters were calculated from bundle block adjustment with self-calibration and with use of all 56 GCPs for the block orientation. It was done to eliminate an impact of possible block deformations on stereoscopic measurements.

The results of the test are as following:

	Xg-Xp (cm)	Yg-Yp (cm)	Zg-Zp (cm)	Xg-Xp (pix)	Yg-Yp (pix)	Zg-Zp (pix)
MIN	-5.10	-6.40	-13.20	-1.27	-1.60	-3.30
MAX	5.90	6.30	18.20	1.48	1.58	4.55
Mean	-0.16	-0.18	2.94	-0.04	-0.04	0.73
STDEV	2.03	2.40	6.87	0.51	0.60	1.72
RMSE	2.04	2.41	7.47	0.51	0.60	1.87

The distribution of dZ residuals may be presented as following:



9. Conclusions

This Phase One iXU-RS1000 Accuracy Assessment Report was dedicated to check the camera's capabilities to be used in high accuracy mapping projects. Only the camera with focal length of 90 mm was tested.

The test preparation included:

1. Test field development with precisely defined and measured GCPs,
2. Tie points automatic measurements (image matching) and GCP measurements with Agisoft Photoscan Pro software,
3. Bundle block adjustment with Bingo software.
4. Stereoscopic measurements with Atlas KLT digital photogrammetric workstation.

The results obtained during the data analysis clearly evidence that:

1. Phase One iXU-RS1000 is a metric camera with stable and clearly definable interior orientation parameters,
2. The images captured by the camera are of high geometric and radiometric quality ensuring the use of the camera in high accuracy mapping projects, including stereocompilation.
3. The final photogrammetric accuracy without use of GNSS data reached 0.5 pixel in position and 1.0 pixel in altitude.
4. The right use and high quality of GNSS data will even improve the results.