Accuracy control at various stages of photogrammetric processing in PHOTOMOD system

This description is based on "Instruction for photogrammetric processing for creating a digital topographic maps and planes" (Moscow, CNIIGAIK, 2002) approved by ***THE FEDERAL AGENCY OF GEODESY AND CARTOGRAPHY of Russia****.*

PHOTOMOD system allows to control execution of operations at all stages of project processing. Below is a list of recommendations of accuracy control at various stages of the project processing.

1. The stage “Aerial triangulation” (PHOTOMOD AT)

PHOTOMOD AT (Aerial Triangulation) is a module of data collection for digital aerial triangulation (phototriangulation) for the block of images. Processing images in **PHOTOMOD AT** includes interior orientation and relative orientation, input and measurements of ground control points, adding tie points in the overlapping areas between adjacent images and strips.

1.1. Interior orientation

For images from an analog camera you should measure fiducial marks on the margins of images. In this case errors of interior orientation are calculated along both axes.

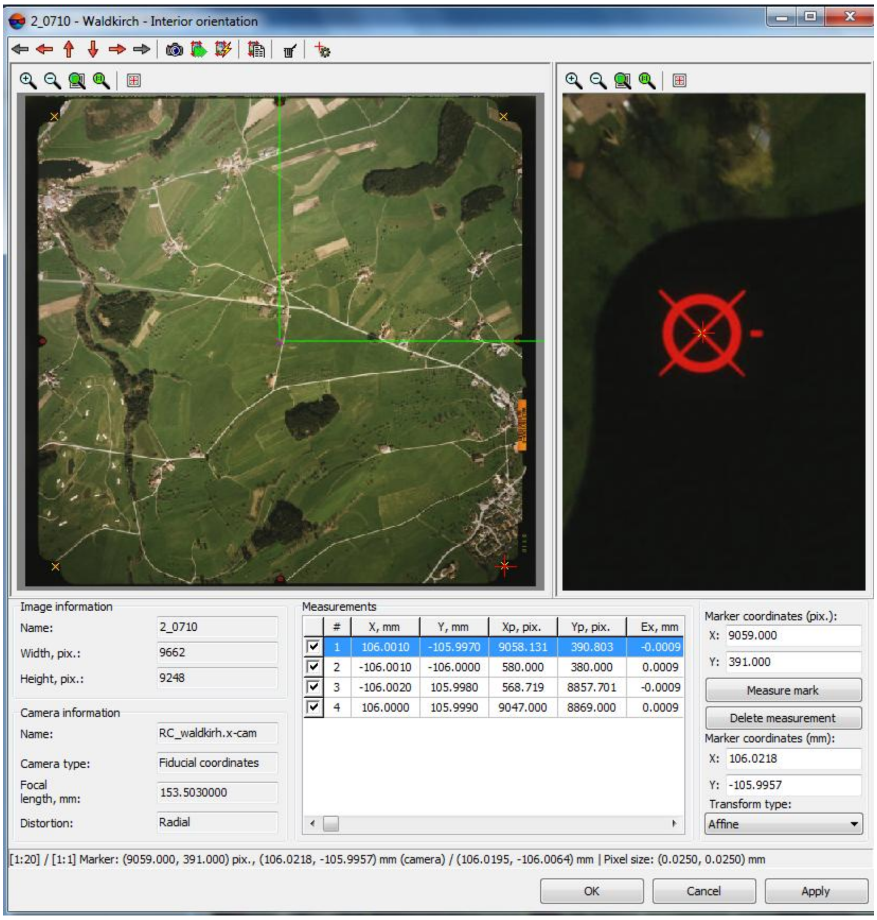

Fig. 1.1. Interior orientation

If scan has carried out by photogrammetric scanner. the acceptable maximum error (**Max**) should not be more than the size of a pixel. For example, if the scan pixel size is 12 mcm. the **Max** should not be more than this value.

For images from digital camera interior orientation is performed in automatic mode. You only need to enter parameters of interior orientation from the camera passport.

1.2. Relative orientation

The process of relative orientation is as follows:
- measuring tie points on stereopairs in overlapping areas and triplet zones;
- measuring tie points between adjacent strips;
- input and measurements of ground control points.

The following tie points position/number is considered as an optimum: tie points are grouped in the special standard zones in the images overlap, at least 2-3 points in each group. See fig.1.2. and 1.3.

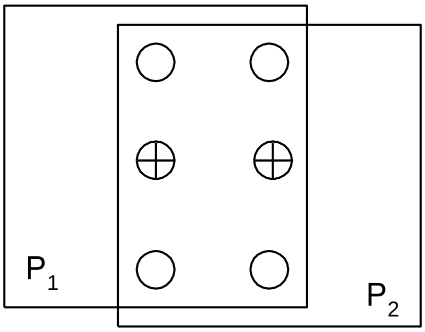

Fig. 1.2. Scheme of standard zones location

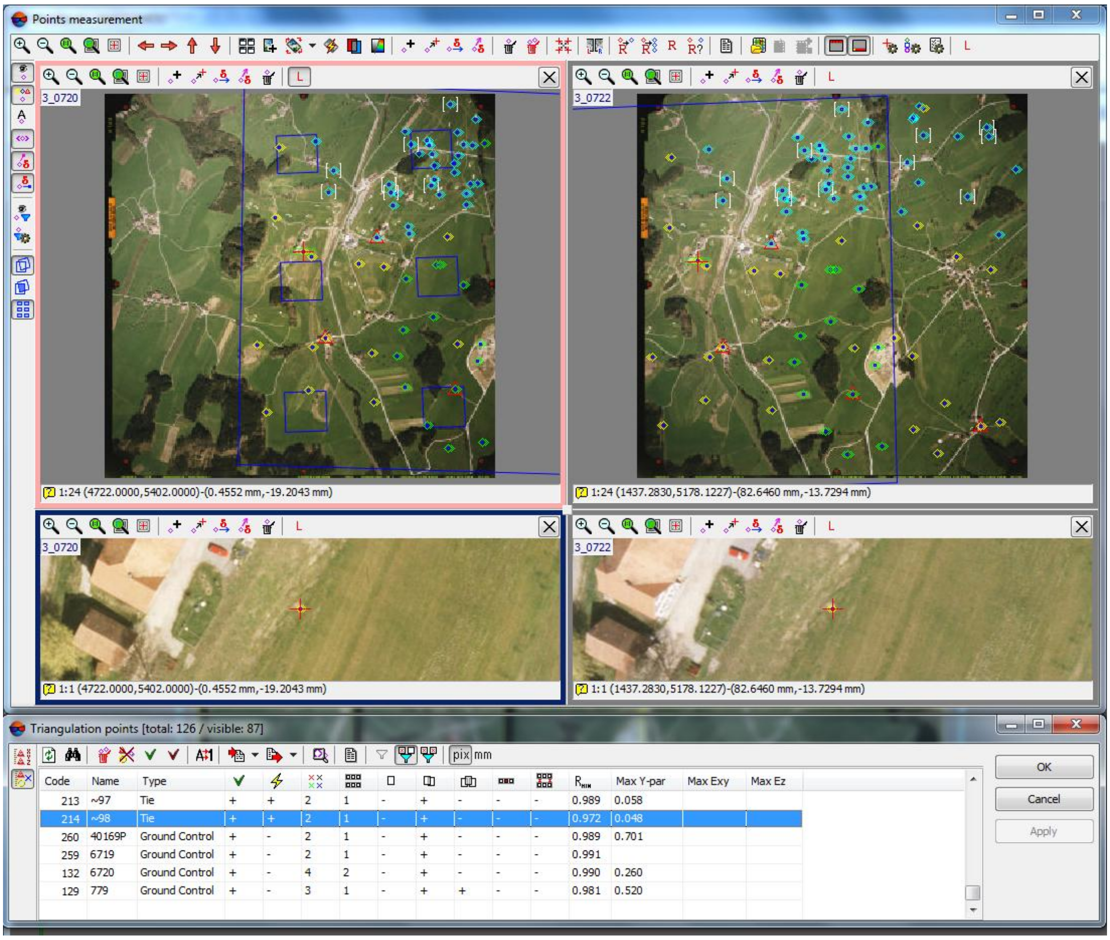

Fig. 1.3. Measuring tie points in the standard zones

This way provides the most accurate and reliable determination of relative orientation parameters with possibility of localization of blunders. We recommend that points in the triple overlap area were, if possible. placed uniformly in this zone.

Measurement quality of tie and ground control points can be checked by the following ways:

1) *accuracy control using correlation coefficient* (if points are added by correlator)
Acceptable value of correlation coefficient can be determined by user from photographic quality of images. For contrast and high quality images the threshold is 0.9 – 0.95. for unclear images the threshold can be 0.8 at well recognized points.

2) *accuracy control using vertical parallax residual*
After measuring 5 points on stereopair, relative orientation parameters of images pairs are calculated and then recomputed more exactly while points being added. The table containing points measured (in the **Measuring tie points** window) shows the values of vertical parallax residual. Measurement units are pixels or millimeters depending on camera units. **Status** window shows **RMS** (root mean squared) and **Max** (maximum) values of vertical parallax residuals. See fig. 1.4.

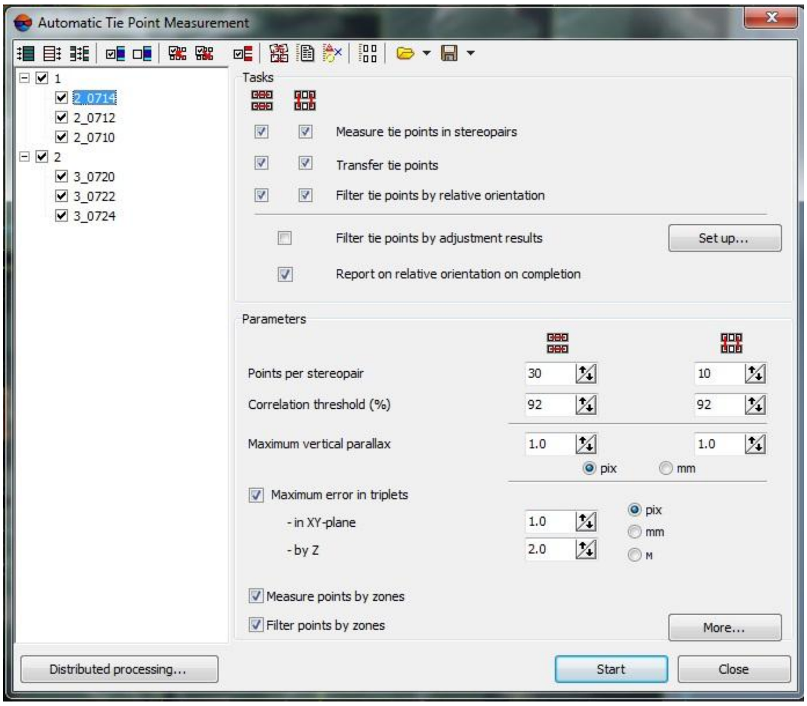

Fig. 1.4. Calculation of relative orientation parameters and vertical parallax residuals

Mean vertical parallax value should not be greater than half of scanning pixel size for analog camera and half of matrix pixel size for digital camera. For example, if the scanning pixel size is 12 microns, the mean value should not be more than 6 microns, while if the matrix pixel size is 9 microns. the mean value should not be more than 4.5 microns.*

For calculation of maximum error (Max) and root mean squared error (RMS) see Appendix 1.

In our case **Max** are 12 microns and 9 microns for analog and digital cameras correspondingly.

3) *accuracy control by adjacent models tying (in triplets)*
After measuring tie points on stereopairs you should transfer points belonging to the triple overlap area of adjacent models (triplet). You can check relative orientation accuracy by comparing the discrepancies of point's measurements on adjacent models (in triplets). In the **Discrepancies on model ties** window the list of all tie points located in overlapping zone is displayed, showing the discrepancies (triplet errors) Ex, Ey, Ez in their X, Y, Z coordinates calculated on two adjacent

models. The errors could be measured in image scale (mm) or real scale (m), depending on the option **Errors scale**. See Fig. 1.6.

Mean triplet errors in XY plane should not be greater than half of pixel size multiplied by √ 2. error by Z equals the mean triplet errors value in XY plane multiplied by the ratio of focal length to survey basis (in image scale). See below:

$$E^{xy}_{mean} = \sqrt{2} \cdot 0.5 pxl$$

$$E^{z}_{mean} = \frac{f}{b} \cdot E^{xy}_{mean}$$

See also Appendix 1.

Approximate aerial survey basis can be calculated by one from next formulas:

1) $b_x = l_x \cdot (100\% - p_x)/100\%$.

Where b_x – survey basis (mm);

l_x – film size along the X-axis (mm);

p_x – size of the overlapping zone in % (60%. in general).

2) $b_x = x_{left} - x_{right}$.

where x_{left} and x_{right} – X-coordinates of the same tie point on left and right images (mm).

You can find out these coordinates in the **Measuring tie points** window. See fig. 1.5.

Later on the combination of words "pixel size**" means the size of scanning pixel for analog cameras and the size of matrix pixel for digital cameras.*

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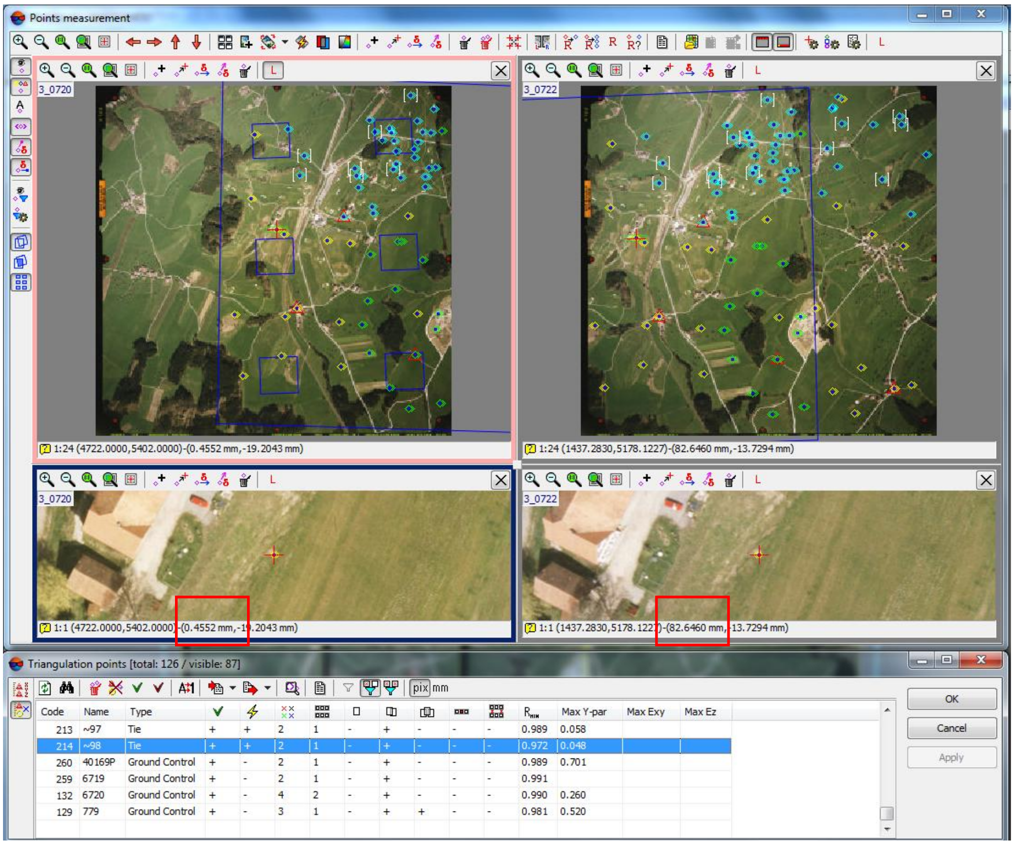

Fig. 1.5. Determination of X-coordinates of the tie point on the left/right images for the basis calculation

Table 1.1. shows acceptable mean triplet errors for 23×23 cm format analog camera images with the pixel size of 12 microns, the overlapping zone size of 60% and three standard focal lengths.

f (mm)	E^{xy}_{mean} (mm)	E^{z}_{mean} (mm)
90	0.008	0.008
150	0.008	0.014
300	0.008	0.028

Table 1.1. Acceptable triplet mean error for analog camera images

See also Appendix 1.

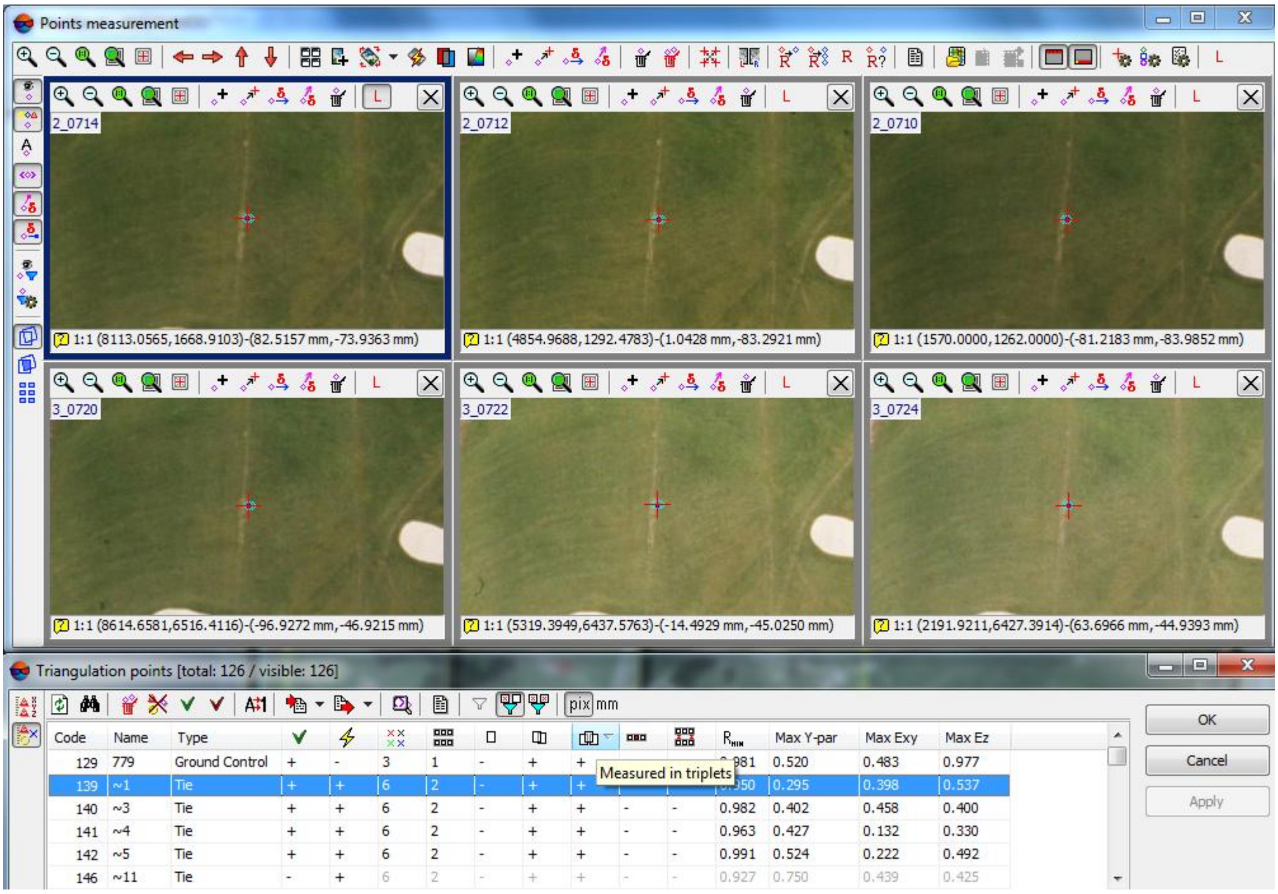

Fig. 1.6. Accuracy control in triplets

Table 1.2. shows acceptable triplet error for images from various digital cameras with the overlapping zone size of 60%.**

Camera	Focal length f (mm)	Pixel size (mm)	Image format (pxl) (mm)	Basis (mm)	E^{xy}_{mean} (mm)	E^{z}_{mean} (mm)
DMC	120	0.012	7680x13824 92.2x165.9	36.9	0.008	0.028
DSS	55	0.009	4092x4077 36.8x36.7	14.8	0.006	0.024
UltraCamD	100	0.009	7500x11500 67.5x103.5	27.0	0.006	0.024
UltraCamX	100	0.007	9420x14430 67.8x103.9	27.1	0.005	0.019

Table 1.2. Acceptable triplet error for digital images

See also Appendix 1.

***survey by digital cameras is frequently made with overlapping of 80-90%, so f|b ratio increases and consequently values of triplets errors Ez increase also.*

After relative orientation execution you should perform tie points measurement between adjacent strips.
Inter-strip tie points measurement to be recommended as follows:

1) Measure 2-3 tie points on the overlapping zone of adjacent strips. It would be better to locate points at the top and at the bottom of the longitudinal overlap;
2) Transfer each inter-strip tie point to at least one adjacent image in each strip taking into control the value of maximum vertical parallax residuals for each stereopair, inside of which a new point was added (the button **Relative Orientation and Triplet Check**).

After inter-strip tie points measurement you should perform relative orientation and triplet accuracy control and then you can pass to the stage “Block adjustment”.

2. Stage “Block adjustment” (PHOTOMOD Solver)

PHOTOMOD Solver program is used to adjust strips and blocks of images. Firstly, you should perform adjustment and check errors in *free* model (without ground control points). These errors allow to estimate the quality of photogrammetric measurement.

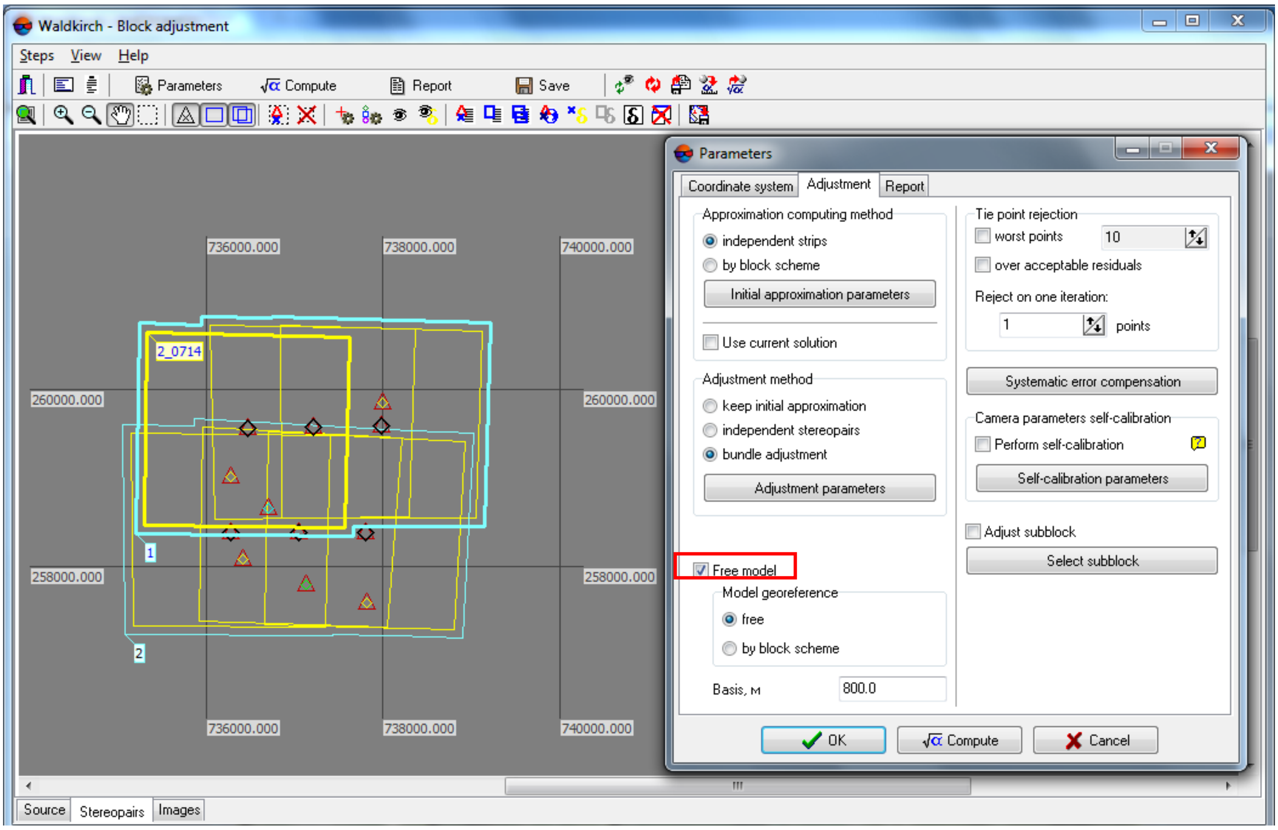

Fig. 2.1 Free model adjustment

To estimate <u>the expected accuracy</u> of the adjustment using ground control points you should specify the survey basis value in free model (in meters) in **Adjustment** tab of **Parameters** window. Also the **Adjustment** tab is used to select the **Block adjustment** method.
If the results of free model adjustment satisfy the specified accuracy you can perform final adjustment using ground control points. The accuracy of this adjustment will be not higher than the accuracy of free model adjustment.
Acceptable errors (residuals) on adjustment stage for various end-products (topographic maps. orthophoto) are listed below.

2.1 Accuracy control of adjustment for topographic maps creation

Ground control points (GCP)
Acceptable mean residuals on GCP after adjustment should not be greater than 0.2 mm in XY plane (in output map (plane) scale) and $0.15 \cdot h_{\text{int}}$ by Z, where h_{int} – contours interval of the output map.

Check points
Acceptable mean residuals on Check points – 0.3 mm in the output map scale.
Acceptable mean residuals on Check points by Z:

1) $0.2 \cdot h_{\text{int}}$ – for contour interval of 1m and also for scale - 1:1000. 1:500 with the contour interval of 0.5 m
2) $0.25 \cdot h_{\text{int}}$ – for contour interval of 2.5 m and also scale - 1:2000 and 1:500 with the contour interval of 0.5 m
3) $0.35 \cdot h_{\text{int}}$ – for contour intervals of 5 m and 10 m

Scale	h_{int} (m)	Mean residuals (m)			
		GCP		Check points	
		In XY plane	By Z	In XY plane	By Z
1:2000	1	0.4	0.15	0.6	0.2
1:10000	2.5	2	0.38	3	0.625
1:25000	5	5	0.75	7.5	1.75

Tab 2.1. Acceptable ground control and check points residuals

See also Appendix 1.

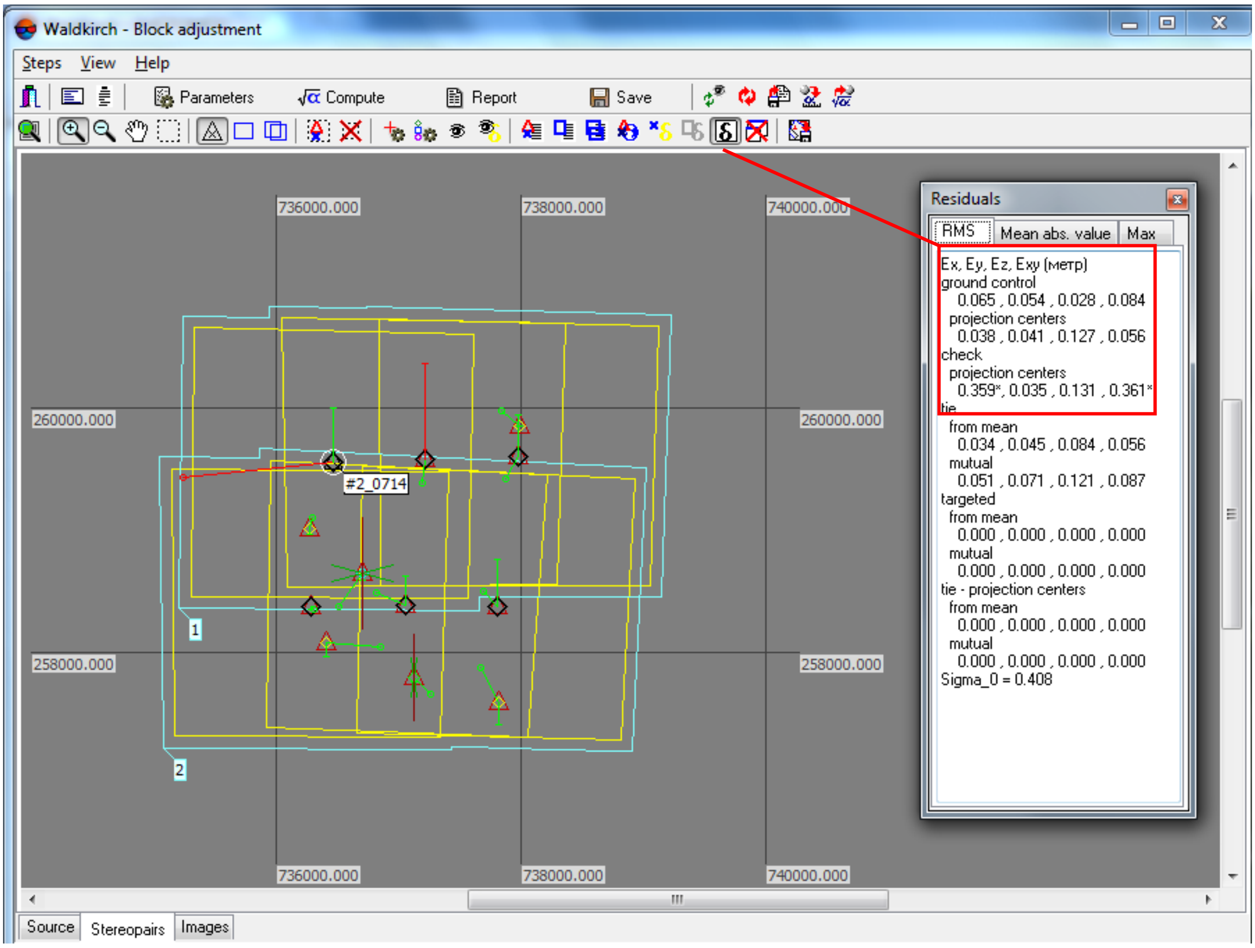

Fig. 2.2. Accuracy control on GCP and check points.

2.2 Accuracy of adjustment for orthophoto creation

Ground control points (GCP)
Acceptable mean residuals on GCP in XYplane – 0.2 mm in output map scale.

Acceptable mean residuals on GCP by Z - $\frac{1}{3}\Delta h_{DTM}$, where Δh_{DTM} – mean residual of DTM.

Check points
Acceptable mean residuals on Check points in XY plane – 0.3 mm (in map (plane) scale).

Acceptable mean residuals on Check points by Z - $\frac{1}{3}\Delta h_{ЦМР}$, where Δh_{DTM} – mean residual of DTM.

See the description of acceptable DTM error Δh_{DTM} in the *“Creating DTM”* section.
Table 2.2.1. shows acceptable mean residuals of adjustment on GCP and Check points for orthophoto creation for 23x23 cm format of *analog images*:

Scale	f (mm)	Mean residuals (m)			
		GCP		Check	
		In XY plane	By Z	In XY plane	By Z
1:2000	90	0.4	0.13	0.6	0.13
	150		0.22		0.22
	300		0.45		0.5
1:10000	90	2	0.67	3	0.67
	150		1.12		1.12
	300		2.24		2.24
1:25000	90	5	1.68	7.5	1.68
	150		2.80		2.80
	300		5.59		5.59

Table 2.2.1. Mean residuals of adjustment on GCP and Check points for orthophoto creation (23x23 cm analog images)

See also Appendix 1.

Table 2.2.2. shows acceptable mean residuals of adjustment on GCP and Check points for orthophoto creation from *digital images*:

Scale	Camera	Mean residuals (m)			
		GCP		Check	
		In XY plane	By Z	In XY plane	By Z
1:2000	DMC	0.4	0.27	0.6	0.27
	DSS		0.51		0.51
	UltraCamD		0.36		0.36
	UltraCamX		0.36		0.36
1:10000	DMC	2	1.37	3	1.37
	DSS		2.57		2.57
	UltraCamD		1.80		1.80
	UltraCamX		1.79		1.79
1:25000	DMC	5	3.43	7.5	3.43
	DSS		6.42		6.42
	UltraCamD		4.50		4.50
	UltraCamX		4.48		4.48

Table 2.2.2. Mean residuals of adjustment on GCP and Check points for orthophoto creation for digital images

See also Appendix 1.

3. Stage “Creating DTM” (PHOTOMOD DTM)

When you create **DTM** you should check its Z-accuracy. depending on the end-product of photogrammetric processing.
See the tables of residuals below (depending on orthophoto scale and survey parameters).

Acceptable mean residual by Z-coordinate Δh_{DTM} for orthophoto creation is calculated by formula:

$$\Delta h_{DTM} = 0{,}3mm \cdot f \cdot \frac{M}{r},$$

where 0.3mm – graphic accuracy of topographic map (XY plane)
f – camera focal length (mm)
M – output map (plane) scale
r – maximum distance from the image point to the nadir point (mm). which equals to the half of diagonal of **“**working area**”**.

If the analog films format is 23x23 cm and the overlapping area - 60%, the overlapping area - 13.8×23 cm and ***r*** equals approximately 134 mm.
Table 3.1. shows acceptable mean residuals Δh_{DTM} (m) for analog films with the working area radius of 134 mm. depending on the map scale and focal length.

Scale	Focal length (mm)		
	90	150	300
1:2000	0.4	0.7	1.3
1:10000	2.0	3.4	6.7
1:25000	5.0	8.4	16.8

Table 3.1. Acceptable mean DTM residuals Δh_{DTM} for analog images with *r* =134 mm.

See also Appendix 1.

Table 3.2. shows the working area radius values for images from various digital cameras with the overlapping area of 60%:

Camera	Film format (pxl / mm)	Basis (mm)	Working area radius (mm)
DMC	7680x13824 92.2x165.9	36.9	87.4
DSS	4092x4077 36.8x36.7	14.8	21.4
UltraCamD	7500x11500 67.5x103.5	27.0	55.6
UltraCamX	9420x14430 67.8x103.9	27.1	55.8

Table 3.2. The working area radius values for digital images with the overlapping area of 60%

Table 3.3 shows acceptable mean DTM residuals Δh_{DTM} (m) for various digital camera images with the overlapping area of 60%. depending on the output orthophoto scale:

Scale	Camera			
	DMC	DSS	UltraCamD	UltraCamX
1:2000	0.82	1.54	1.08	1.08
1:10000	4.12	7.70	5.40	5.38
1:25000	10.29	19.25	13.50	13.44

Table 3.3. Acceptable mean residuals Δh_{DTM} (m) for digital images (overlapping area - 60 %)

See also Appendix 1.

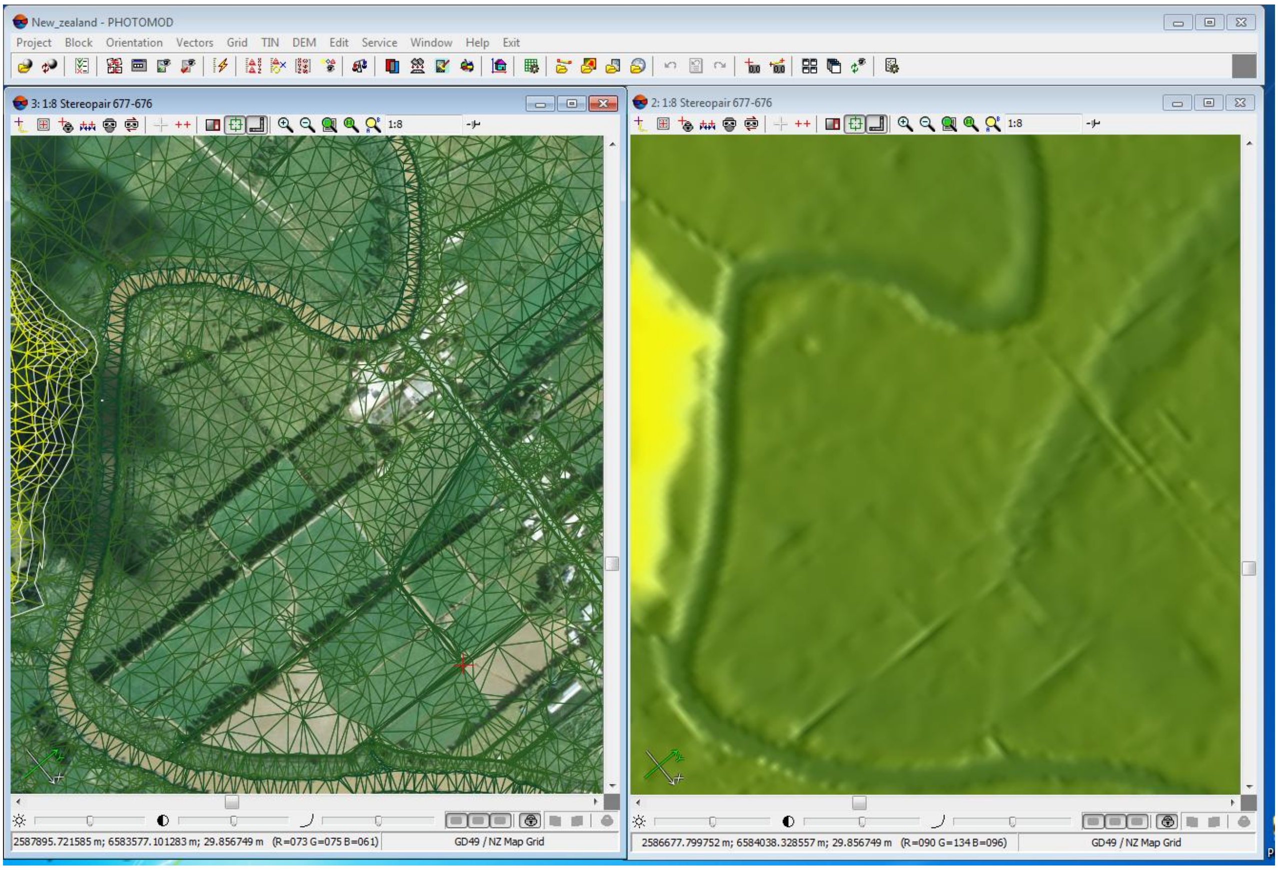

Fig. 3.1. DTM as TIN and DEM

4. Stage “Orthomosaic creation” (PHOTOMOD Mosaic)

Accuracy control of orthophoto is carried out on ground control/check points and as well as along the cutlines.

Acceptable GCP/Check points residuals in XYplane are 0.5 mm for flat and hilly regions and 0.7 mm for mountainous regions in orthophoto scale.

The orthoimage quality is also controlled by measuring the conjunction of corresponding objects from adjacent images along the cutlines. Acceptable values of this error are 0.7 mm for flat and hilly regions and 1 mm for mountainous regions in the orthoimage scale.

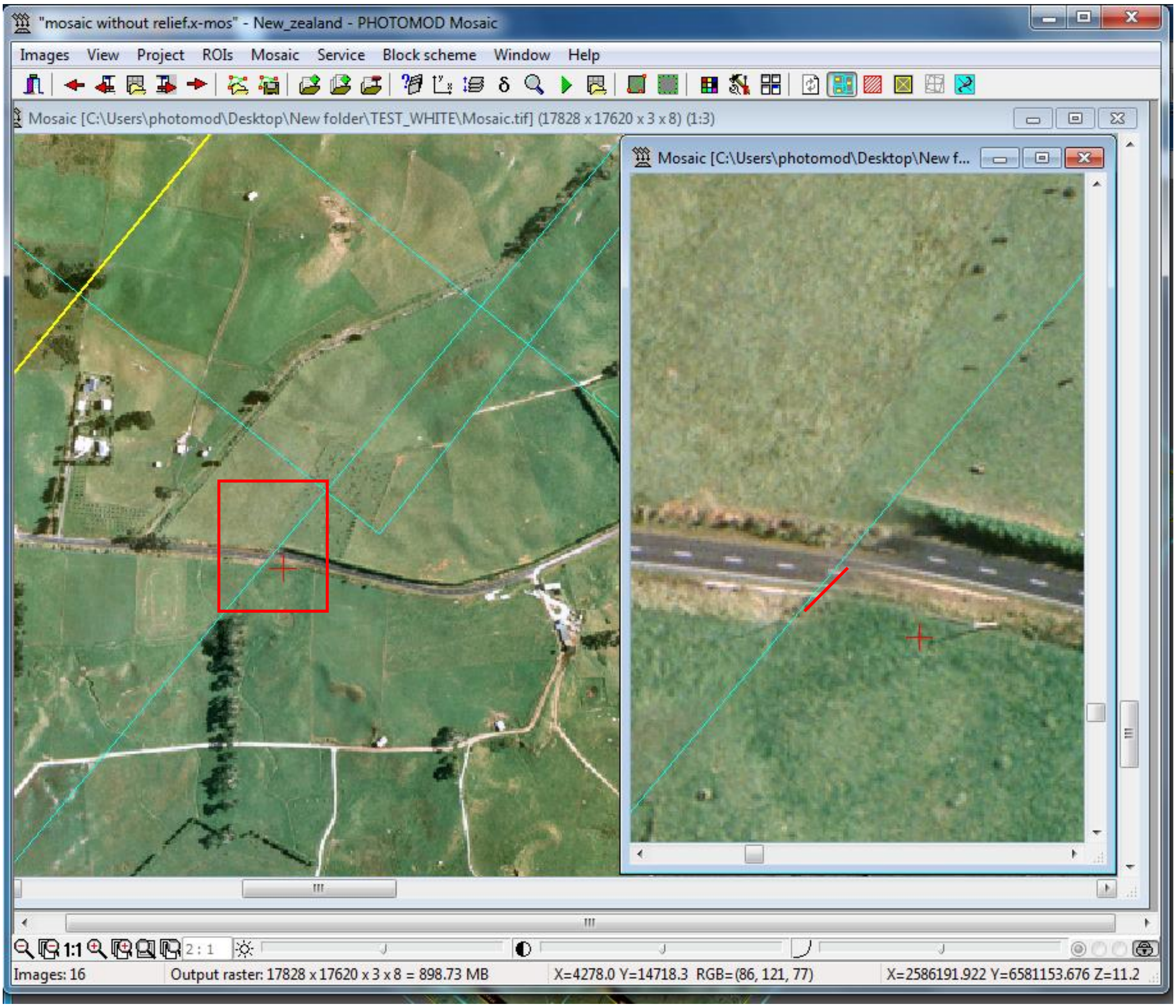

Fig. 4.1 Objects conjunction error

You can check accuracy on GCP/Check points automatically (button **Accuracy control**). The table 4.1. shows acceptable GCP/Check points residuals (in XYplane), depending on orthophoto scale.

Scale	E_{mean}^{xy} (m)	
	Flat and hilly regions	Mountainous regions
1:2000	1	1.4
1:10000	5	7
1:25000	12.5	17.5

Table 4.1. Acceptable GCP/Check points residuals. depending on orthophoto scale

See also Appendix 1.

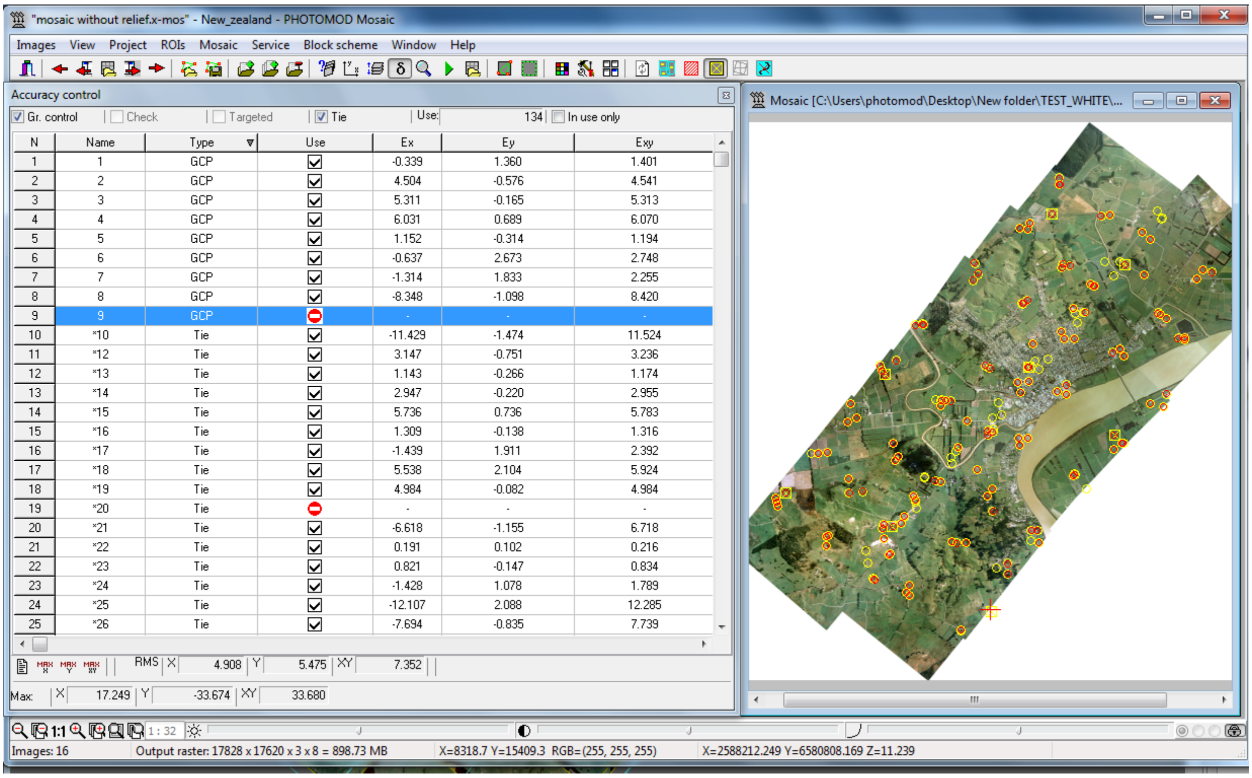

Fig. 4.2. Automatic accuracy control on GCP/Check points.

Appendix 1

Approximate ratio of mean. maximum error and root mean squared errors:

$$E_{\max} \approx 2 \cdot E_{mean}\ ;$$
$$RMS \approx \sqrt{2} \cdot E_{mean}\,,$$

where E_{mean} - mean error;

$E_{\max}$ - maximum error;

RMS - root mean squared error.

References:

1. A. N. Lobanov. M. I. Burov. B.V. Kracnopevtsev. The Photogrammetry. – Moscow: Nedra, 1987.
2. A. P. Mikhailov. A. G. Chibunichev. The photogrammetry lectures. – Moscow, 2005.
3. The recommendations by photogrammetric processing for digital topographic maps/plans. – Moscow: CNIIGAIK, 2002.