Digital Photogrammetric System

PHOTOMOD

Version 8.1

USER MANUAL

Block adjustment (Windows x64)

RACURS

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1. Purpose of the document

This document contains detailed information about block adjustment procedure in *PHOTOMOD* system's window. Here there is a description of project types and methods of block adjustment of both central projection images and scanner images, distinguishing features of the methods, ways of adjustment accuracy control. The document also describes special aspects of adjustment of different images blocks and accuracy control of various types of projects on stage of projects processing in.

2. General information

Block adjustment could be performed of both central projection images and scanner space images.

The adjustment is a process of calculation exterior orientation parameters and coordinate measurement of all points in the block.

It is necessary to have interior and relative orientation of block images available to start block adjustment.

Block adjustment is performed after stage of data collection for phototriangulation, internal and relative images orientation, measurement of ground control points (GCP) (see "Aerial triangulation" User Manual).

Minimal requirement for block adjustment is available results of interior and relative orientation of block images.

For adjustment of images block it is necessary to preliminary setup of adjustment parameters – specify coordinate system, select adjustment method, choose main adjustment parameters, setup report parameters and define residuals threshold of adjustment.

The system provides the following adjustment methods for adjustment of central projection images block:

- *Initial approximation independent strips method* or *initial approximation using block scheme* is basically used to reveal blunders, such as incorrectly specified ground control points coordinates, errors of tie points positioning, etc.;
- *independent stereopairs method* is used to increase accuracy of adjustment results, obtained during initial approximation calculation; to recognize small errors and in case of acceptable results, for final adjustment;
- *Bundle adjustment* is used for final block adjustment;

In many cases it is advisable to use *independent stereopairs method* and *bundle adjustment* alternatively to recognize and fix small errors.

- *Free model* – block adjustment without georeference data. When free model is created it is possible to pass directly to project processing (vectorization, TIN and DEM creation). Therefore, when GCP coordinates will be obtained the main work with project will be completed.

  Note that the accuracy of the output products obtained as a result of processing a project adjusted according to a free model is, in most situations, sufficient only for overview purposes.

After interior and relative orientation it is necessary to measure GCP coordinates and adjust a block in selected coordinate system. After that all data obtained during processing project (vector objects, TIN and DEM) created in free model, will be transformed in selected coordinate system.

The system provides the following adjustment methods for adjustment of scanner images block:

- *Rigorous method* – the method allows to consider exterior orientation parameters from metadata obtained from RS data provider;
- *RPC-method* – the method uses RPC-coefficients from metadata obtained from RS data provider;
- *Generic method* – the method uses parallel-perspective model or *Direct Linear Transformation* (DLT) algorithm, that allows to process *any* scanner images (including IRS, LandSat, etc.). However this requires more ground control points per stereopair as compared to rigorous method;
- *Import of adjustment* – import of images exterior orientation parameters from metadata for ADS 40/80/100 projects.

After images block adjustment the system provides possibility to view adjustment report for adjustment accuracy control, to edit points position for adjustment errors recovery, to save and export adjustment results of block scheme. Besides, the system allows to import adjustment results, acquired in third party software packages for further project processing using these data.

3. The “Block adjustment” toolbar

The **Block adjustment** additional toolbar is used for adjustment of images block.

To show the **Block adjustment** toolbar choose the **Orientation › Block adjustment (Ctrl+Alt+S)** or click the button on the main system toolbar.

Table 1. The “Block adjustment” toolbar

Buttons	Function
	to load or restore current status of a block (load adjustment results after reloading project)

Buttons	Function
	to open window used to setup parameters of block adjustment (see Section 7 and Section 8)
	to start the adjustment procedure
	to open window allowing to create the report with results of block adjustment (see Section 10)
	o save results of block adjustment in order to pass to the next stage of project processing in the system
	to reset block to initial state
	[only for central projection] to export adjustment results for further adjustment in third party software
	[only for central projection] to import adjustment results obtained using third party software
	to display a toolbar of displaying triangulation points settings
	to show the *Triangulation points* window with a list of all triangulation points of a project (ground control, check, and tie) and also to view, search, edit, and import/export points
	to show/hide the bar with values of RMS, mean absolute and maximal adjustment residuals. The window is intended for quick results estimation without viewing of detailed report (see Section 6)
	to show/hide the **Point attributes** bar with information about selected point and possibility to manage a type of points (see Section 5.5)
	to select on a block scheme types of points chosen in the window (see Section 5.5)

4. Adjustment batch mode

The system also provides block adjustment in batch mode. Perform the following actions to do this:

1. Start the server/client of distributed processing mode (see the “Distributed processing” chapter in the “General information” User Manual).

2. Choose **Orientation › Adjustment in batch mode** or click the button on the **AT** additional toolbar. The **Parameters** window opens.

3. Setup parameters of central projection or scanner image block adjustment.

4. Click OK. Distributed processing tasks are created and the system shows a message about number of created tasks.

5. Objects displaying settings

5.1. Parameters of points and error display on a block scheme

The system provides setup of display of triangulation points on the block scheme and display errors on points.

To setup objects display is used the **Display options** window. Click the button on the **Adjustment** toolbar to open it.

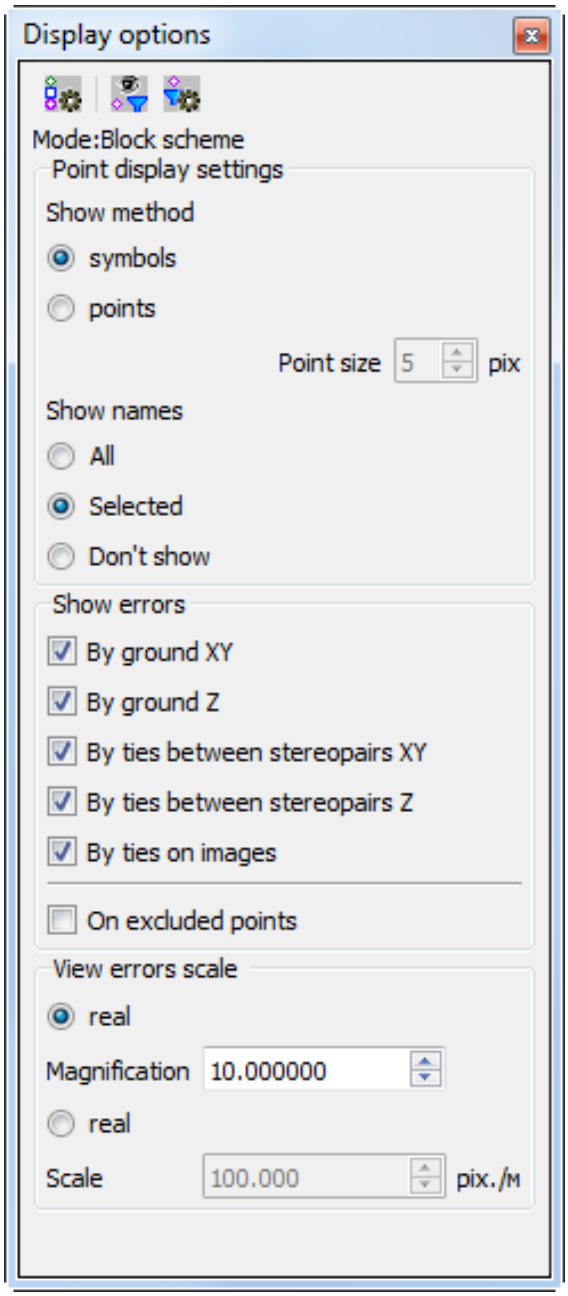


Fig. 1. Parameters of triangulation points display

The **Display options** window contains the toolbar with buttons used to perform the following operations:

- – allows to display a list of points symbols on a block scheme;
- – allows to set on/off the filter of triangulation points display;

- – allows to setup the filter of triangulation points display;

In the `Mode:` field is displayed chosen mode of block scheme, it depends on active 2D-window – `Block scheme` or `Image`.

Triangulation points are not displayed in the stereopair 2D-window.

The **Point display settings** section allows to setup the following parameters:

- The **Show method** of points:
  - **symbols** – allows to display all points by symbols;
  - **points** – allows to display by points and also to specify the point size in pixels.
- **Show names** the following points in 2D-window:
  - **All** points;
  - **Selected** points;
  - **Don't show** points names on a block scheme.

The **Show errors** section allows to choose errors of different types to display in 2D-window:

- **By ground XY** – vector with beginning in point's center, directed to specified point's position, with small circle at the end;
- **By ground Z** – vertical vector, with small horizontal bar at the end.

Vectors mentioned above are displayed by green color, if residuals are within specified threshold. If the residuals exceed the threshold, they are shown by red color.

- **By ties between stereopairs XY** – sidelong cross with size proportional to residuals values by X and Y;
- **By ties between stereopairs Z** – vertical line, directed symmetrically up and down in relation to point; the line's size corresponds to residuals values by Z;
- **By ties on images** – circle with center in point's center and with size proportional to residuals values.

Vectors mentioned above are displayed by dark green color, if residuals are within specified threshold. If the residuals exceed the threshold, they are shown by dark red color.

Residuals vectors with `by ties` types are not displayed in single image 2D-window.

Residuals vectors displaying (depending on its size) also could be changed in the **Auxiliary** section of the **Select points** window (see the Section 5.3);

The **On excluded points** checkbox allows to show residuals for points excluded from adjustment.

View scale section allows to manage zoom of residuals vectors display on a block scheme in accordance with selected scale option:

- **real** scale – residual vector size (size of circle with a cross) corresponds to a scheme scale, i.e. for residuals on GCP/check points the end of error vector indicates point with user defined coordinates at zoom "*x1*" (one to one) , that allows to see position of erroneously recognized GCP. At that vectors are zoom in/out during zooming in/out of block scheme (see and Section 5.2);
- **screen** scale – in the field is used to specify number of units of coordinate system (meters, feet) in 100 screen pixels.

The **Display options** window is located at the left or right part of the 2D-window by default. The system interface is flexible for customizing the locations this window according to the user's needs.

The **Display options** window can either be fixed in designated sections of the work area (right or left) or undocked by the user and placed in any place in the 2D window.

To undock the **Display options** window (or pinpoint it in any place), move the cursor over the window title and, holding down the **left mouse button**, drag the window to the area of its targeted location.

Use the button on the right side of the window title to undock a docked window.

To quickly return a window to the area where it was docked last time, double-click the **left mouse button** on the window title

Several similar windows docked within one work area make up a group of tabs. To go to the desired tab, **left-click** on its title.

5.2. Setup of points symbols

Unique symbol and different colors can be used for each type of points on a block scheme.

The **Symbols** window allows to display symbols list, change symbol or color. To open the window click the button of the **Display options** window toolbar.

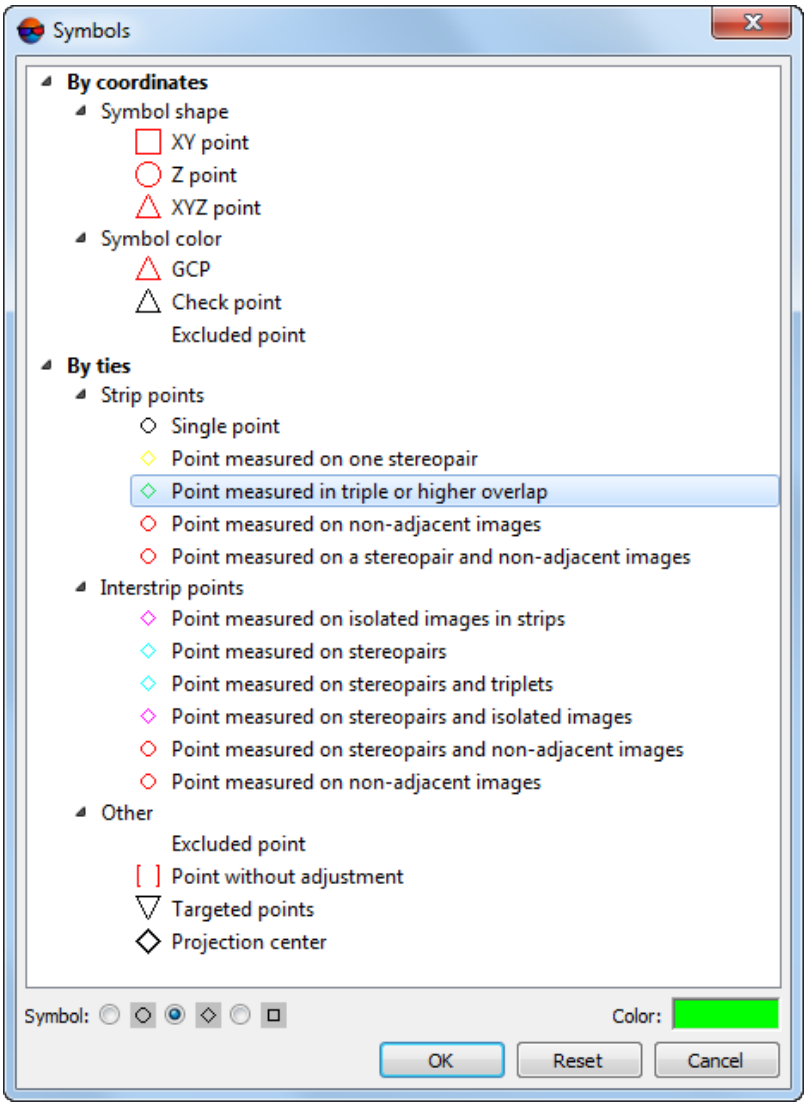


Fig. 2. The Symbols window

For points with known coordinates the following symbols are used:

- *points with known X,Y coordinates* – rectangle ;
- *points with known Z coordinates* – circle ;
- *points with known X,Y,Z coordinates* – triangle program.

For points with known coordinates the following symbol colors are used:

- *for GCP* – red color ;
- *for check points* – black color ;
- *for points excluded from adjustment* (C) – white color .

By default for *tie strip* points there are the following shapes and colors of symbols:

- single point – black circle;
- measured on a single stereopair – yellow rhombus;
- measured in triple or more overlap– green rhombus;
- measured on non-adjacent images – red circle;
- measured on a stereopair and its non-adjacent images – red circle.

By default for *tie interstrip* points there are the following shapes and colors of symbols:

- measured on single images in strips – crimson rhombus;
- measured on stereopairs – turquoise rhombus;
- measured on stereopairs and triplets – turquoise rhombus;
- measured on stereopairs and single images – crimson rhombus;
- measured on stereopairs and non-adjacent images – red circle;
- measured on non-adjacent images – red circle.

For the rest points there are the following shapes and colors of symbols:

- *excluded* – white square brackets ;
- *without adjustment* – red square brackets;
- *targeted points* – black upturned triangle ;
- *projection centers* – black rhombus .

A point could be displayed on a block scheme as combination of one, two or more symbols.

To change shape and color of tie points symbol (both strip and interstrip) perform the following actions:

1. [optional] Click the button on the **Block adjustment** toolbar to show the **Display options** window.
2. Click the button of the **Display options** window toolbar. The **Symbols** window is opened.
3. In the **By ties** list select a point type which symbol or color needed to be changed.

4. Select **Symbol** to define a point's shape – circle ○, rhombus ◇ or square □.

5. Click the **Color** field and select necessary color from standard color palette of *Windows*.

6. [optional] To go back to default marker size use the **Reset** button.

7. Click OK to confirm changes.

5.3. Points filter

It is possible to choose points for display on the block scheme. The **Point filter** window is used for that.

To open the **Point filter** window, in the **Display options** window click the button.

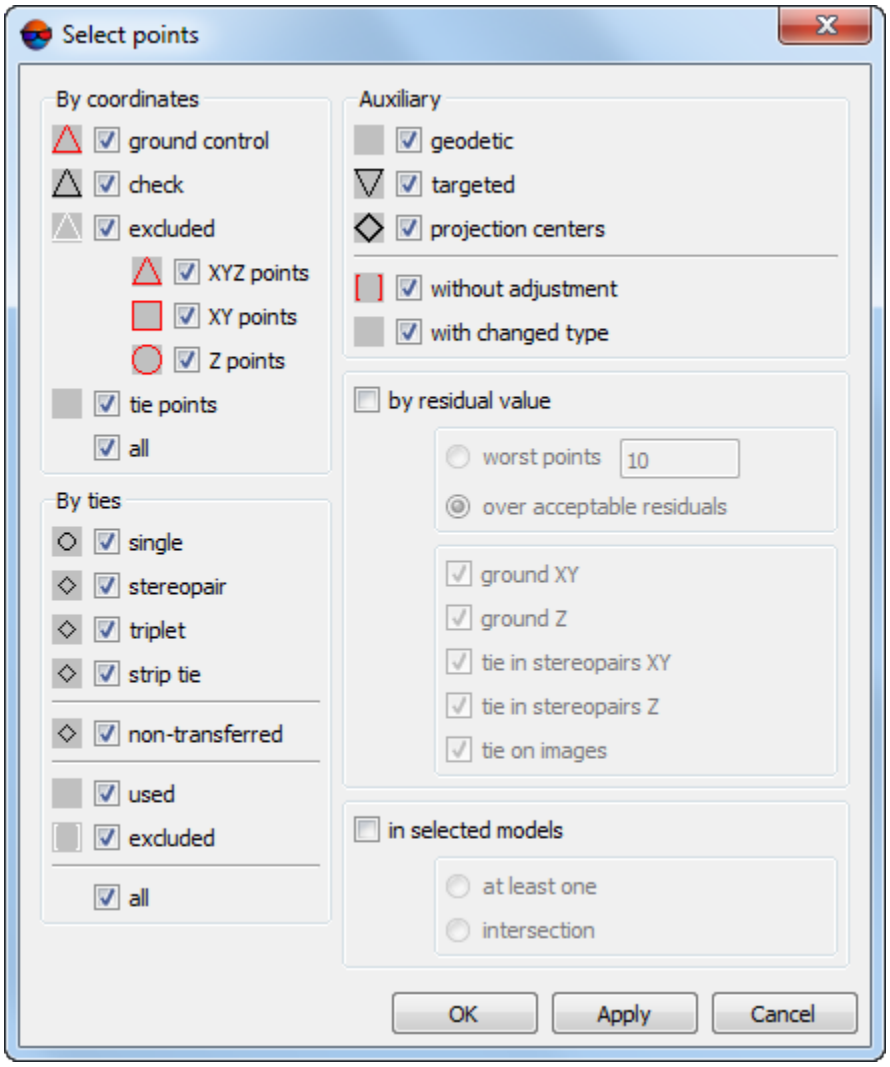


Fig. 3. The Point filter window

To display points on a block scheme special – symbols.

The **Select points** window contains the following sections which are used to make points selection using different criteria:

- the **By coordinates** section is used to select points depending on their coordinates:
  - **ground control** points (ground and projection centers);
  - **check** points (ground and projection centers);
  - **excluded** – points with known coordinates, excluded from adjustment;
  - **tie points** – points without geodetic coordinates (if the checkbox is set off, only ground control points are displayed);
  - **all** – allows to set on/off all checkboxes of section.

  XYZ, **XY** and **Z points** checkboxes allows to choote type of displayed **ground control, tie and excluded** points.

- the **By ties** section is used to select points depending on number of point's coordinates measurements on image:
  - **single** – points not measured on any stereopair;
  - **stereopair** – points measured on at least one stereopair;
  - **triplet** – points measured at least in one triplet;
  - **strip tie** – points measured in interstrip overlap;
  - **non-transferred** – tie points not measured on adjacent images;
  - **Used** – tie points used in adjustment;
  - **Excluded** – tie points excluded from adjustment;
  - **All** – allows to select/unselect all points mentioned in the section.

- the **Auxiliary** section is used to select points depending on their type:
  - **Geodetic** – tie points which are not targeted and projection centers;
  - **Targeted** – targeted points;
  - **Projection centers** – projection centers;
  - **with changed type** – points with type that was changed during adjustment.

- the **By residual value** section allows to select points depending on residual value on the point:
  - **Worst points** – points with maximal residuals (number of points to be displayed is specified in the appropriate field);
  - **Over acceptable residuals** – points with residuals, exceeding threshold.

    Acceptable residuals are setup in the **Parameters** window on the **Report** tab (see Section 7.4 or Section 8.4).

    Points selection by residuals value is performed using additional checkboxes **Ground XY**, **Ground Z**, **Tie in stereopairs XY**, **Tie in stereopairs Z**, **Tie on images**.

    Residuals are also could be displayed using checkboxes in the **Show errors** section of the **Display options** window.

- **In selected models** – used to select points located in selection area of stereopair/strip or multiple steropairs/strips:
  - **At least one** – points with measurements located in one selection area;
  - **All** – points with measurements located in all selection areas.

To **Apply** the specified settings of point display, click the appropriate button without closing the **Point filter** window.

Ensure that the button is enabled in the **Display options** window.

5.4. Points selection

Triangulation points on a block scheme could be selected using standard group selection tools. To change the selection mode are used the **Edit › Group selection** menu and the **Tools** toolbar. (see the “Objects selection” chapter of the “Vectorization” User Manual).

Also the system provides possibility to highlight points of selected types on a block scheme.

Click the button to select points to be highlighted. The **Select points** window is opened.

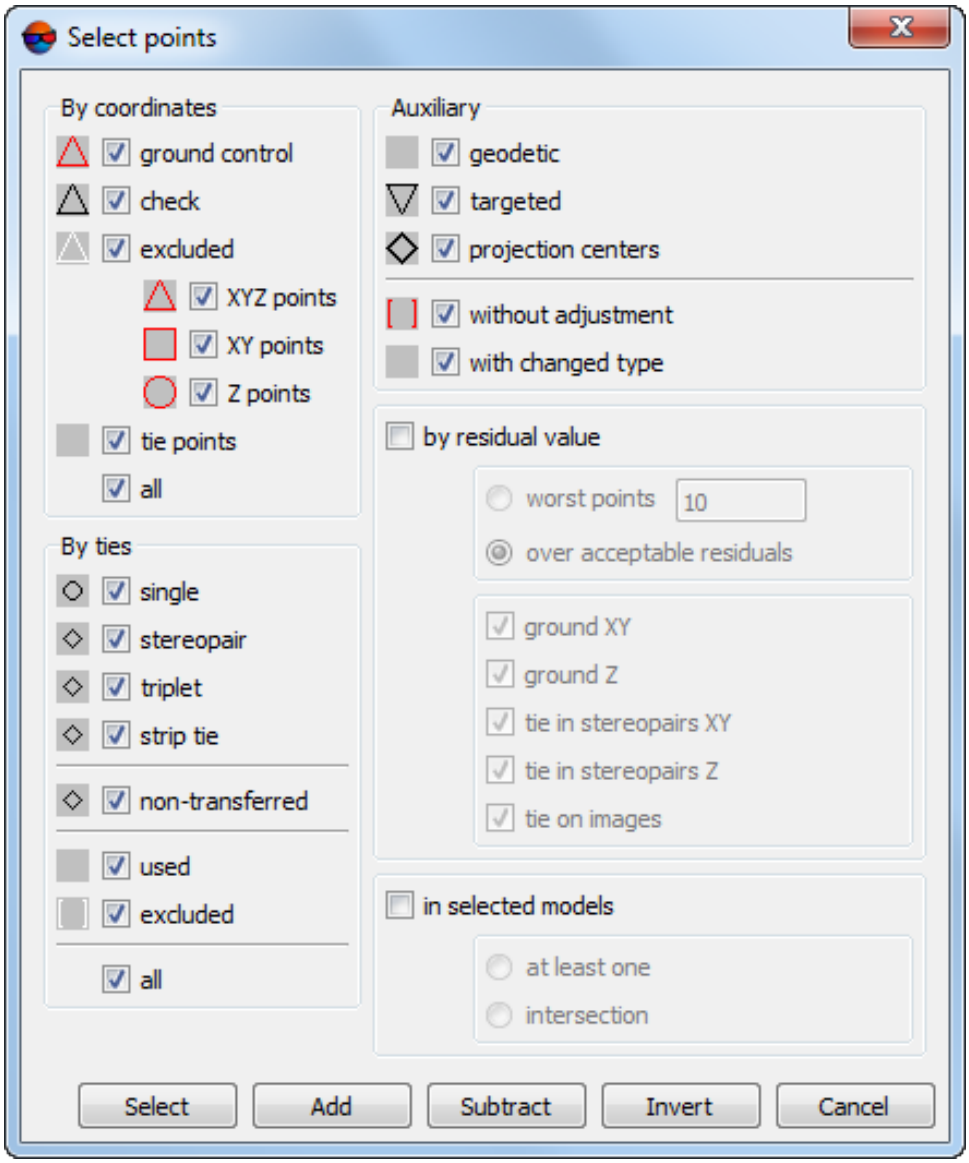


Fig. 4. The Select points window

To display points on a block scheme special – symbols.

The **Select points** window contains the following sections which are used to make points selection using different criteria:

- the **By coordinates** section is used to select points depending on their coordinates:
  - **ground control** points (ground and projection centers);
  - **check** points (ground and projection centers);
  - **excluded** – points with known coordinates, excluded from adjustment;

- **tie points** – points without geodetic coordinates (if the checkbox is set off, only ground control points are displayed);
- **all** – allows to set on/off all checkboxes of section.

XYZ, **XY** and **Z points** checkboxes allows to choote type of displayed **ground control, tie and excluded** points.

- the **By ties** section is used to select points depending on number of point's coordinates measurements on image:
  - **single** – points not measured on any stereopair;
  - **stereopair** – points measured on at least one stereopair;
  - **triplet** – points measured at least in one triplet;
  - **strip tie** – points measured in interstrip overlap;
  - **non-transferred** – tie points not measured on adjacent images;
  - **Used** – tie points used in adjustment;
  - **Excluded** – tie points excluded from adjustment;
  - **All** – allows to select/unselect all points mentioned in the section.
- the **Auxiliary** section is used to select points depending on their type:
  - **Geodetic** – tie points which are not targeted and projection centers;
  - **Targeted** – targeted points;
  - **Projection centers** – projection centers;
  - **with changed type** – points with type that was changed during adjustment.
- the **By residual value** section allows to select points depending on residual value on the point:
  - **Worst points** – points with maximal residuals (number of points to be displayed is specified in the appropriate field);
  - **Over acceptable residuals** – points with residuals, exceeding threshold.

Acceptable residuals are setup in the **Parameters** window on the **Report** tab (see Section 7.4 or Section 8.4).

Points selection by residuals value is performed using additional checkboxes **Ground XY**, **Ground Z**, **Tie in stereopairs XY**, **Tie in stereopairs Z**, **Tie on images**.

Residuals are also could be displayed using checkboxes in the **Show errors** section of the **Display options** window.

- **In selected models** – used to select points located in selection area of stereopair/strip or multiple steropairs/strips:
  - **At least one** – points with measurements located in one selection area;
  - **All** – points with measurements located in all selection areas.

The **Select**, **Add**, **Subtract** and **Invert** buttons are used to perform corresponding operations with selected types of points.

5.5. The “Point attributes” window

The system provides possibility to view such attributes of triangulation points as type, coordinates and residuals. The **Point attributes** window is used to do this.

To open the **Point attributes** window click the button on the **Adjustment** toolbar.

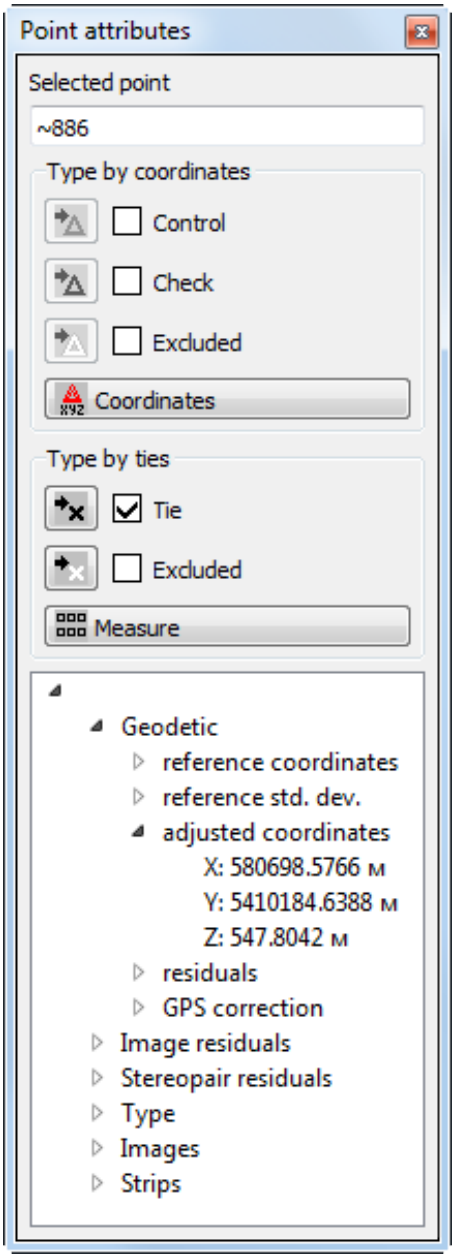


Fig. 5. The Point attributes window for selected point

The **Point attributes** window consists of two sections: in the upper part of the window the editing panel is displayed; in the lower part of the window there is informational panel.

The **Selected point** field shows a name of highlighted point if a single point is highlighted. Or it contains a message about number of highlighted points.

A type of highlighted point is checked in the appropriate field of the **Type by coordinates** section.

The **Type by coordinates** section contains the following buttons:

- – allows to set selected point as a GCP;
- – allows to set selected point as a check point;
- – allows to exclude selected check point or GCP from further adjustment;
- – allows to add excluded tie point to adjustment;
- – allows to exclude tie point from further adjustment.

When a group of points of the same type (check, for instance) is selected, buttons allow to change type of all selected points.

In order to view the selected points in the **Triangulation points** window, click the **Coordinates** button in the **Type by coordinates** section. The **Triangulation points** window opens.

In the **GCP list** and **Tie points** list tabs of the **Triangulation points** window, only selected points will be shown.

If ground control points were among the selected points, the **GCP list** tab will be initially open in the **Triangulation points** window. Otherwise, the **Tie points** list tab will be first open in the **Triangulation points** window.

Double-click on point name in the **Triangulation points** window allows to open the **Points measurement** module to edit point's position.

In order to change the coordinates of the selected points, click the **Measure** button in the **Type by ties** section. The **Points measurement** and the **Triangulation points** windows are opened (see the "Aerial triangulation" User Manual).

Only those selected points coordinates of which are to be changed will be shown in the **GCP list** and **Tie points** list tabs of the **Triangulation points** window.

If ground control points were among the selected points, the **GCP list** tab will be initially open in the **Triangulation points** window. Otherwise, the **Tie points** list tab will be first open in the **Triangulation points** window.

Section in the lower part of the **Point attributes** window contains information about selected point.

Information field contains any information only when just *one point* is selected on a block scheme.

In the section are displayed the following settings of selected point:

- **Geodetic** – information about GCP and check points:
  - **reference coordinates** – initial (user defined) coordinates of point;

  - **reference std. dev.** – initial weights of selected point coordinates;
  - **adjusted coordinates** – coordinates of point, obtained after adjustment;
  - **residuals**.
- **Image residuals**:
  - **residuals (max)** – maximal residuals on images for selected point;
  - **number of images**, where selected point coordinates were measured;
  - **images** – displays number of images where point's coordinates were measured. For each of the images tie residuals are displayed (to average adjusted position) and also point's measurements on image, coordinates of projection on image of point's adjusted position. For GCP and check points there are also coordinates of projection of initial geodetic coordinates on image.
- **Stereopair residuals**:
  - **residuals (max)** – maximal residuals on images for selected point;
  - **number of stereopairs**, where selected point coordinates were measured;
  - **by stereopairs** – displays `residuals from mean value` and `mutual residuals` for each stereopair with selected point.
- **Type** – information about point's type, whether it is a projection center, a code of selected point (image code for projection centers) is also shown here);
- **Images** – list of images, where selected point coordinates were calculated;
- **Strips** – list of strips, where selected point coordinates were measured (on one image at least).

The **Point attributes** window is located at the left or right part of the 2D-window by default. The system interface is flexible for customizing the locations this window according to the user's needs.

The **Point attributes** window can either be fixed in designated sections of the work area (right or left) or undocked by the user and placed in any place in the 2D window.

To undock the **Point attributes** window (or pinpoint it in any place), move the cursor over the window title and, holding down the **left mouse button**, drag the window to the area of its targeted location.

Use the button on the right side of the window title to undock a docked window.

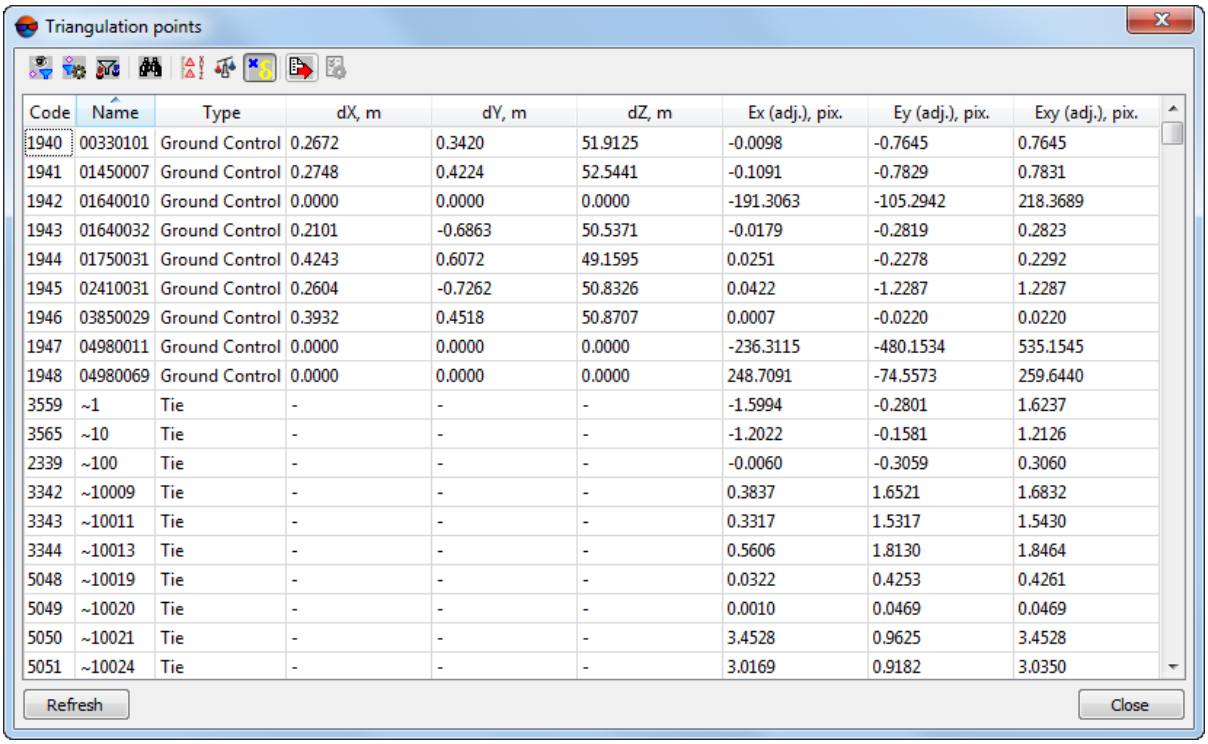
To quickly return a window to the area where it was docked last time, double-click the **left mouse button** on the window title

Several similar windows docked within one work area make up a group of tabs. To go to the desired tab, **left-click** on its title.

5.6. List of triangulation points

The system provides possibility to view, search and edit of triangulation points. The **Triangulation points** window is used to do this.

To open the **Triangulation points** window click the button on the **Adjustment** toolbar or choose **Window › Triangulation points coordinates** .



Code	Name	Type	dX, m	dY, m	dZ, m	Ex (adj.), pix.	Ey (adj.), pix.	Exy (adj.), pix.
1940	00330101	Ground Control	0.2672	0.3420	51.9125	-0.0098	-0.7645	0.7645
1941	01450007	Ground Control	0.2748	0.4224	52.5441	-0.1091	-0.7829	0.7831
1942	01640010	Ground Control	0.0000	0.0000	0.0000	-191.3063	-105.2942	218.3689
1943	01640032	Ground Control	0.2101	-0.6863	50.5371	-0.0179	-0.2819	0.2823
1944	01750031	Ground Control	0.4243	0.6072	49.1595	0.0251	-0.2278	0.2292
1945	02410031	Ground Control	0.2604	-0.7262	50.8326	0.0422	-1.2287	1.2287
1946	03850029	Ground Control	0.3932	0.4518	50.8707	0.0007	-0.0220	0.0220
1947	04980011	Ground Control	0.0000	0.0000	0.0000	-236.3115	-480.1534	535.1545
1948	04980069	Ground Control	0.0000	0.0000	0.0000	248.7091	-74.5573	259.6440
3559	~1	Tie	-	-	-	-1.5994	-0.2801	1.6237
3565	~10	Tie	-	-	-	-1.2022	-0.1581	1.2126
2339	~100	Tie	-	-	-	-0.0060	-0.3059	0.3060
3342	~10009	Tie	-	-	-	0.3837	1.6521	1.6832
3343	~10011	Tie	-	-	-	0.3317	1.5317	1.5430
3344	~10013	Tie	-	-	-	0.5606	1.8130	1.8464
5048	~10019	Tie	-	-	-	0.0322	0.4253	0.4261
5049	~10020	Tie	-	-	-	0.0010	0.0469	0.0469
5050	~10021	Tie	-	-	-	3.4528	0.9625	3.4528
5051	~10024	Tie	-	-	-	3.0169	0.9182	3.0350

Fig. 6. The Triangulation points window

The **Triangulation points** window contains the toolbar with buttons used to perform the following operations:

- – allows to set on/off the filter of triangulation points display;
- – allows to setup the filter of triangulation points display;
- – allows to display all/selected on a block scheme points in the table;
- – is used to search for an image by name (part of name);

- – allows to display GC/check points initial coordinates (`X, Y, Z` – see the ’Aerial triangulation” User Manual);
- – allows to display triangulation points coordinates obtained after adjustment (`X', Y', Z'`);
- – allows to display errors on points:
  - `dX, dY, dZ` – error values on point;
  - `Ex(adj.), Ey(adj.), Exy(adj.)` – average residuals of points on images;
  - `Esp_x(adj.), Esp_y(adj.), Esp_z(adj.)` – tie residuals between stereopairs.
- – is used export the table content to text file with `*.csv` extension;
- – allows specify the following **Error settings**:

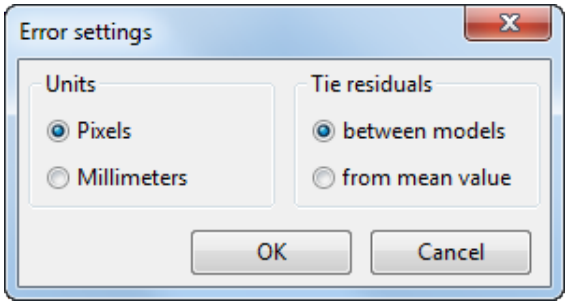


Fig. 7. The Error settings window

  - to set the following **units** of `Ex(adj.)`, `Ey(adj.)` and `Exy(adj.)` errors displaying – for the central projection projects:
    - **pixels**;
    - **millimeters**.

For satellite scanner imaging and ADS 40/80/100 projects, error data are displayed only in pixels.

  - to select method of calculation **tie residuals** calculation between stereopairs (`Esp_x(adj.), Esp_y(adj.), Esp_z(adj.)`):
    - **between models** – tie residuals from difference of the same point positions, calculated on each stereopair;
    - **from mean value** – tie residuals from difference of the same point position, calculated on each stereopair and its mean adjusted position.

The **Refresh** button is used for refreshing data in triangulation points table after changes.

The list of triangulation points is a table with the following columns:

- `Code` – an object code;
- `Name` – image name;
- `Type` – displays point's type (tie, GCP, check, excluded);
- `X, Y, Z` – GC/tie point initial coordinates ( );
- `X', Y', Z'` – adjusted coordinates of triangulation points ( );
- `dX, dY, dZ` – error values on point ( );
- `Ex(adj.), Ey(adj.), Exy(adj.)` – average residuals of points on images ( );
- `Esp_x(adj.), Esp_y(adj.), Esp_z(adj.)` – tie residuals between stereopairs ( ).

The **Triangulation points** window is synchronized with 2D-window: when point selecting in 2D-window it is also selects in the table. Double-click by row with point allows to open the **Points measurements** module to edit point's position.

The system provides possibility to edit position of triangulation points selected in 2D-window in the **Points measurements** module. Perform the following actions to do this:

1. Select points in 2D-window with one of the group selection instruments (see the "Vectorization" User Manual).
2. In the **Triangulation points** click the button to show in the table only points selected in 2D-window.
3. In the Point attributes window click the **Measure** button. The **Points measurement** module opens (see Section 11).

   In the **Triangulation points** window is displayed list of points, selected in 2D-window.
4. Edit points position and click OK to return to the adjustment step.

6. Brief residuals report

The system allows to display brief residuals report, which contains RMS errors, mean absolute and maximal adjustment errors.

Brief residuals report is used for quick estimation of adjustment results without viewing detailed report.

In order to display brief residuals report, click the button on the **Adjustment** toolbar. The **Residuals** window opens.

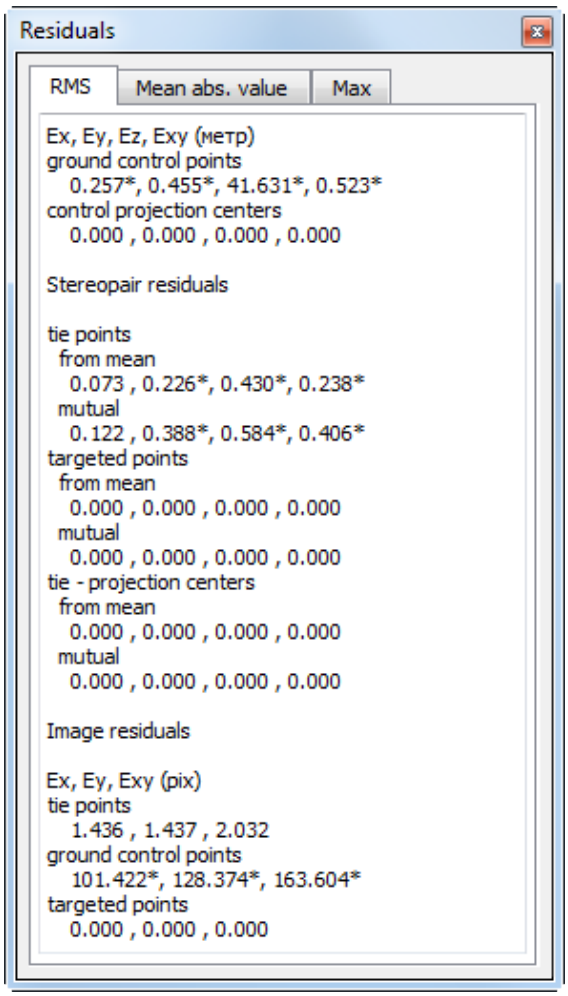


Fig. 8. The Residuals window

The brief report contains information about mean absolute errors on GCP and check points (in meters), about tie and targeted points, as well as about tie residuals on projection centers (*mutual* and *from mean* residuals).

If adjustment is performed by bundle adjustment procedure, the `Sigma_0` value is calculated.

The `Sigma_0` value shows how much adjustment discrepancies correspond to specified thresholds on points coordinates measurements and input GCP data (GCP and projection centers coordinates). If the thresholds were specified correctly, the `Sigma_0` has value close to 1 (±30%).

If the `Sigma_0` is much greater than 1, there are errors in points coordinates measurements, in input GCP data or because of incorrectly specified thresholds on points coordinates measurements. If the `Sigma_0` is mush less than 1, the threshold on points coordinates measurements were specified incorrectly or there are some other errors (see Section 10).

The **Residuals** window is located at the left or right part of the 2D-window by default. The system interface is flexible for customizing the locations this window according to the user's needs.

The **Residuals** window can either be fixed in designated sections of the work area (right or left) or undocked by the user and placed in any place in the 2D window.

To undock the **Residuals** window (or pinpoint it in any place), move the cursor over the window title and, holding down the **left mouse button**, drag the window to the area of its targeted location.

Use the button on the right side of the window title to undock a docked window.

To quickly return a window to the area where it was docked last time, double-click the **left mouse button** on the window title

Several similar windows docked within one work area make up a group of tabs. To go to the desired tab, **left-click** on its title.

7. Adjustment of central projection images block

7.1. Workflow during adjustment of central projection images block

The system allows to process images of central projection.

Central projection images include airborne images, close range images, satellite images of central projection (see "Project creation" User Manual).

Setup adjustment parameters of central projection images block, selection of adjustment method and adjustment model is performed using the **Parameters** window.

To open the **Parameters** window click the button on the **Adjustment** toolbar.

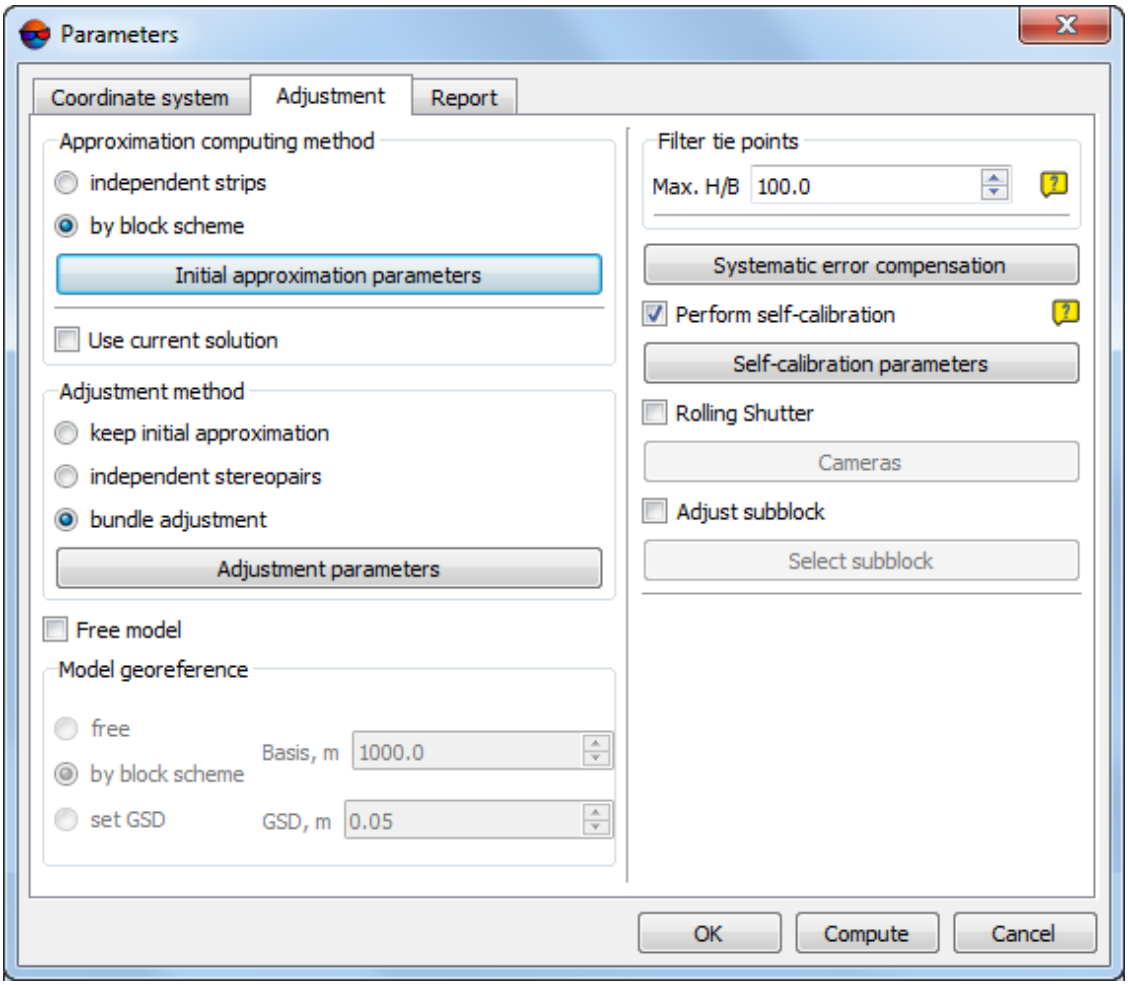


Fig. 9. Parameters of adjustment of central projection images block

In order to setup adjustment parameters perform the following actions:

1. Specify coordinate system of a project on the **Coordinate system** tab.

2. Select the adjustment method and setup main parameters of adjustment on the **Adjustment** tab.

3. Setup display of adjustment results on report and define adjustment residuals threshold using the **Report** tab.

4. Click the **Compute** button to start the adjustment operation or click OK to save the settings and close the **Parameters** window.

7.2. The “Coordinate system” tab

The **Coordinate system** tab allows to specify coordinate system, if it wasn’t specified on project creation stage, or allows to change current coordinate system (see “*Coordinate system selection*” chapter in the “Project creation” User Manual).

It is not necessary to define coordinate system for block adjustment in free model.

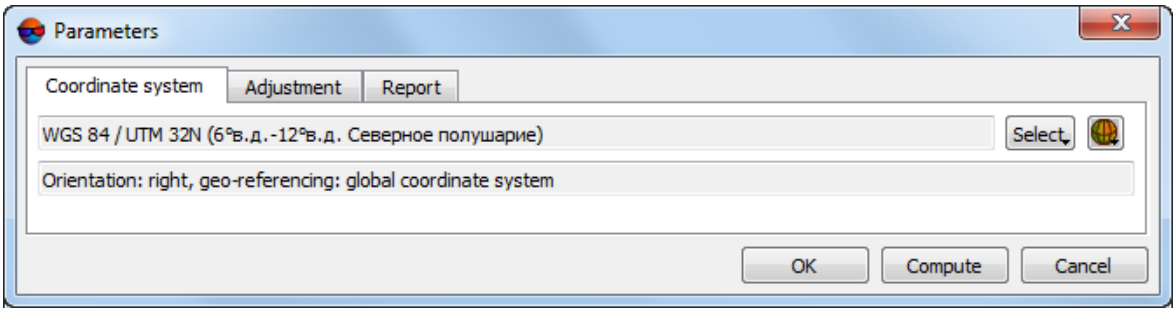


Fig. 10. Parameters of adjustment

7.3. The “Adjustment” tab

7.3.1. Adjustment parameters of central projection images block

The **Adjustment** tab allows to choose method and model of adjustment of central projection images block, and also to setup adjustment parameters.

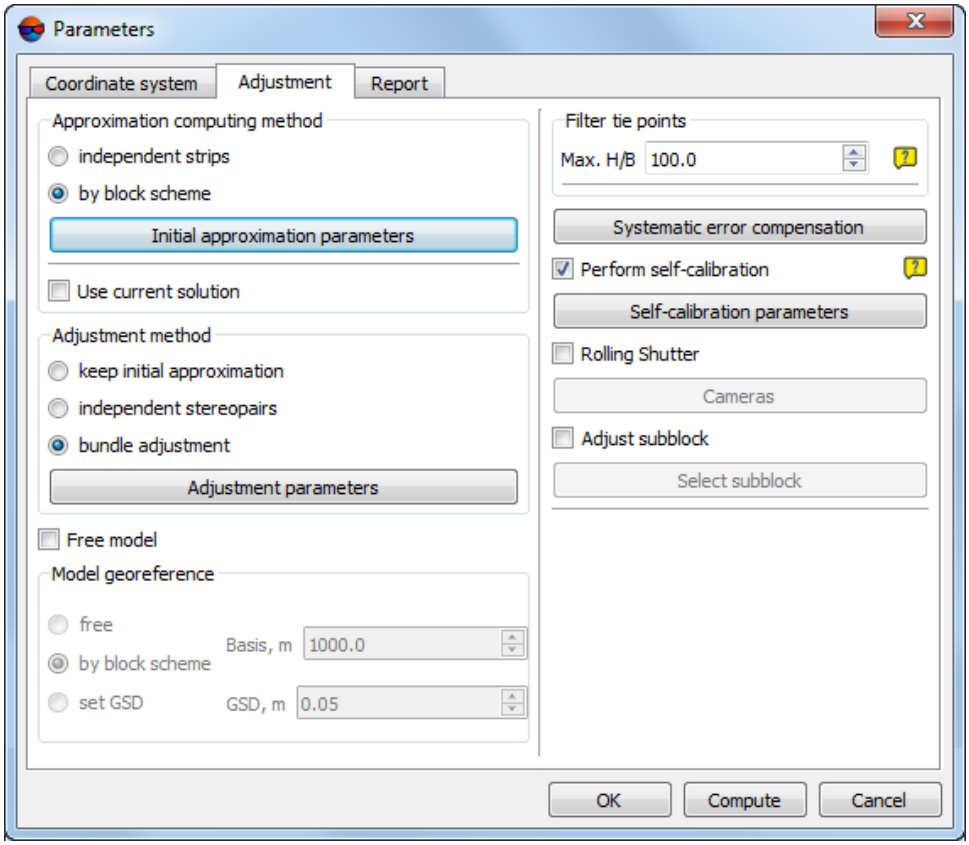


Fig. 11. Parameters of adjustment

In order to setup adjustment parameters of central projection images check if georeference data is available (measured GCP coordinates or exterior orientation parameters) and perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.

2. Click the **Adjustment** tab.

3. In case of georeference data is unavailable or not enough, it is recommended to perform adjustment in free model. To do this set the **Free model** checkbox and select one of the following georeference models:

   - **free** – during adjustment the system performs rotation, zoom and shift of projection centers coordinates in such a way that X,Y,Z coordinates of projection center of the first image of block are 0,0,0, of the second – b,0,0, where b – value of basis in meters specified in the **Basis** field;

   - **by block scheme** – during adjustment the system performs rotation, zoom and shift of projection centers coordinates in accordance with block layout.

   - **Set GSD** (pixel size) – if the relevant data is available, the user can set an approximate average pixel size in the block images. After adjustment, the rotation, scaling, and shift of projection center coordinates are carried out accounting for the maximum reduction of the average block pixel size to the specified size.

     The approximate average pixel size is set by the user based on available information about the survey conditions and the parameters of the camera – the focal length and the matrix size used for the video recording – as well as the average flight altitude of its carrier.

     The user-set GSD value is automatically stored up by the system and can be used, after adjustment, to perform further work.

   Adjustment in free model allows to perform control of blunders in tie points measurements.

4. In the **Approximation computing method** section choose method and specify parameters of first approximation:

   - **independent strips** – during adjustment independent models by images in each strip are creating (using tie points between images) and further joining to common model. After that performs orientation by GCP in selected geodetic coordinate system;

     It is necessary to have enough amount of points measured in triplets to use method of independent strips. This allows to quickly adjust block which contains big number of images.

- **by block scheme** – adjustment using current block scheme of block layout for approximate adjustment considering results of all block measurements.

5. [optional] In order to use previous adjustment results in new adjustment session, set the **Use current solution** checkbox. This allows to use results obtained during previous step of adjustment and not calculate the values again.

   It is used in those cases when iterations of adjustment disagree, some measurements are corrected and the process starts again, for example, when there are lack of points measurements in triplets for images blocks acquired from UAV or they are insufficient.

6. In the **Adjustment method** section choose method and specify parameters of selected method:

   - **keep initial approximation** – aerial triangulation using initial approximation results;

     The method is used to search for blunders, such as incorrectly specified coordinates of GCP.

     For “rough” adjustment of images block acquired from UAV, set the **keep initial approximation** checkbox and adjust block using the **Initial approximation methodby block scheme**.

   - **independent stereopairs** – preliminary aerial triangulation by stereopairs of independent models and their further merging into common block and orientation of the block network in geodetic coordinate system;

   - **bundle adjustment** – aerial triangulation and block adjustment by all images at once is used for final adjustment.

7. In **Tie points rejection** section set the parameters, allowing to exclude from adjustment tie points with small convergence angles. To do this input the **Max. H/B** (Heigh above the ground / Basis) parameter, allowing specify the minimum acceptable convergence angle.

8. [optional] For automatic calculation and compensation of systematic measurement errors click the **Systematic errors compensation** button.

9. [optional] For automatic calculation of camera parameters during adjustment (if in project using incomplete set of camera data or when it is necessary to refine the data), set the **Perform self-calibration** checkbox and click the **Self-calibration parameters** button.

10. [optional] To take the *rolling shutter* effect into account when adjusting a project, set the **Rolling shutter** checkbox and click the **Cameras** button. The **Cameras** window opens:

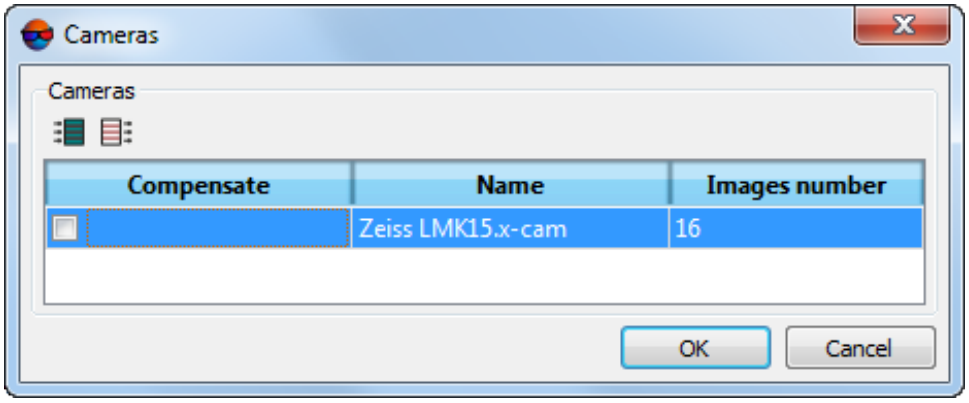


Fig. 12. The Cameras window

Select cameras whose technical characteristics require *rolling shutter* compensation when adjusting a project that contains images taken with those cameras. Click Ok.

Click the button to select all cameras in the project. Click the button to deselect all cameras.

The effect of *rolling shutter* is the distortion of object shapes in an image when a picture is not captured at the same instant but the image is captured progressively. This effect appears at the short shutter speed of focal plane shutters or interline transfer CCD.

Survey data containing such distortions can be obtained using cameras installed aboard some UAS. It is recommended to use *rolling shutter* compensation algorithms if appropriate information about the properties of the equipment used is available.

11. [optional] In order to select project images for adjustment set the **Adjust subblock** checkbox and click the **Select subblock** button.

12. Click OK to save parameters or **Compute** to start the adjustment process.

Recommendations for processing a project with images captured using a focal plane shutter camera

Use the **Rolling shutter** option (see above) only when working with data captured using a focal plane shutter camera.

To ensure the required accuracy of the results obtained, it is advisable to follow the recommendations described below:

- Use GCPs measured with high accuracy;
- Ensure complete connectivity of block images. Tie points must be measured in sufficient quantity on all stereo pairs and on all triplets;

- Correctly set a priori accuracy of the exterior orientation parameters – precision of a priori RMS of measurements of projection center coordinates and exterior orientation angles (**Precision (std.dev)**, when importing exterior orientation parameters);
- Correctly set a priori accuracy of measurements of GCP and tie points on images (**Image measurements RMS** when setting adjustment parameters);
- Only images of areas with flat terrain and no high-rise objects are suitable for stereo processing.

7.3.2. Adjustment in free model

Adjustment in *free model* allows to adjust a block without georeference data. Adjustment in free model to perform control of blunders in tie points measurements.

To perform block adjustment in *free model* perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.
2. Click the **Adjustment** tab.
3. Set the **Free model** checkbox.
4. Select one of the following types of model georeference:
   - **free** – during adjustment the system performs rotation, zoom and shift of projection centers coordinates in such a way that X,Y,Z coordinates of projection center of the first image of block are 0,0,0, of the second – b,0,0, where b – value of basis in meters specified in the **Basis** field;
   - **by block scheme** – during adjustment the system performs rotation, zoom and shift of projection centers coordinates in accordance with block layout.
   - **Set GSD** (pixel size) – if the relevant data is available, the user can set an approximate average pixel size in the block images. After adjustment, the rotation, scaling, and shift of projection center coordinates are carried out accounting for the maximum reduction of the average block pixel size to the specified size.

     The approximate average pixel size is set by the user based on available information about the survey conditions and the parameters of the camera – the focal length and the matrix size used for the video recording – as well as the average flight altitude of its carrier.

     The user-set GSD value is automatically stored up by the system and can be used, after adjustment, to perform further work.
5. Specify the rest of adjustment parameters.

After interior and relative orientation it is necessary to measure GCP coordinates and adjust a block in selected coordinate system.

In order to adjust a block in selected coordinate system after its adjustment in free model, perform the following actions:

1. Adjust a block in free model.
2. Measure coordinates at least of three GCP or load data about at least of three projection centers.
3. On the **Adjustment** tab of the **Parameters** window set the **Free model** checkbox off.
4. Set the **Use current solution** checkbox.
5. In the **Adjustment method** section select the **Keep initial approximation** option.
6. Adjust the block. All data of project processing (vector objects, TIN and DEM) created in free model, transform to selected geodetic coordinate system.

7.3.3. Independent strips method

Independent strips method is used to perform first approximation. This method consists in preliminary creation of independent models using images of each strip (by tie points measured between images) and further joining of the models into integrated model. Then the model is orientated by GCP in geodetic coordinate system.

Independent strips method is applied in general to reveal blunders, such as incorrectly specified GCP coordinates or errors in positioning of tie points.

Prior to adjustment using *independent strips method* check a direction of coordinate system. If the coordinate system is turned at 180° in relation to geodetic coordinate system, perform one of the following actions:

- reverse the strips order;
- reverse images in the strip order;
- turn all images to 180°;
- use another coordinate system with reversed axis orientation;
- change signs of X and Y coordinates of all GCP to opposite (only when perform the adjustment in Cartesian coordinate system).

In order to calculate initial approximation using *independent strips method* perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.

2. Click the **Adjustment** tab.

3. In the **Approximation computing method** section select the **independent strips** method.

4. Click the **Initial approximation parameters** button. The **Independent strips adjustment parameters** window opens.

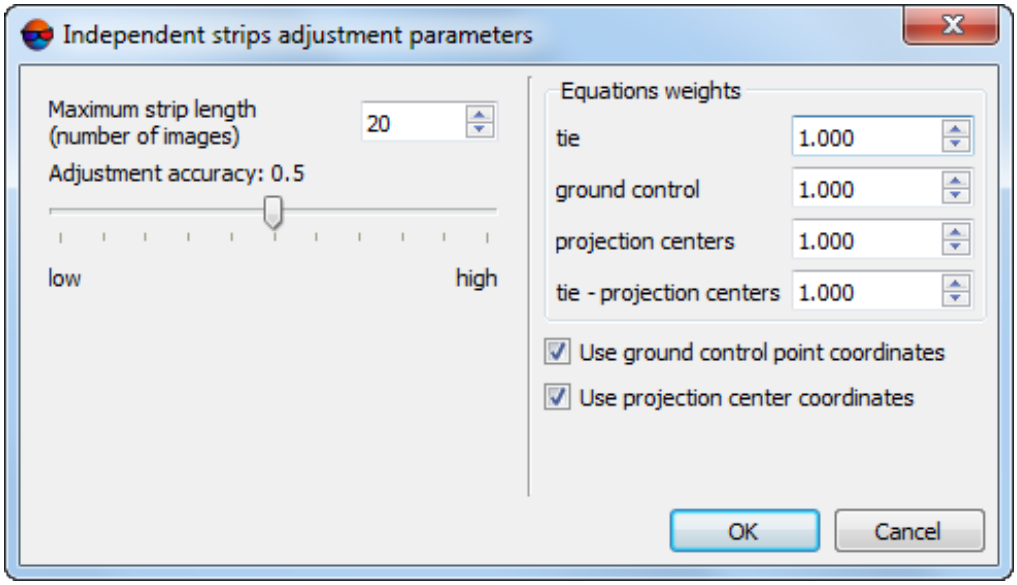


Fig. 13. The Independent strips adjustment parameters window

5. In the **Maximum strip length (number of images)** input field set number of images, on which each strip will be divided. This parameter is used to decrease a number of systematic errors inside strips, which bring to adjustment blunders when strips are more than 20-30 images in length.

   It is recommended to set the value of the parameter within 10-30 images. Strips that have more images will be divided into part of specified size during adjustment procedure.

6. Set the **Adjustment accuracy** slider to a value, at which the system should complete iterative adjustment procedure.

   It is recommended to use the value 0.5 (it is set by default). When it equals 0.5-0.55, the adjustment process converges and provides an optimal ratio “accuracy-time”. If you increase the value more than 0.5, the accuracy generally does not improve considerably, but processing time may increase very much up to infinite looping of iterations (in this case you may use the **Stop** button to stop the adjustment process). If the accuracy value is less then 0.5 the adjustment time is reducing due to accuracy decreasing. The algorithm of optimization has a complex nature, that is why the dependence of adjustment time and accuracy from this parameter value is nonlinear.

7. [optional] In the **Equation weights** field input the values of weights for GCP and tie points, as well as for projection centers to reduce adjustment errors.

   Considerable change of equation weights values leads to reducing of actual adjustment accuracy. There is some optimal value, at which the accuracy is maximal. In most cases the weight value of 1 is near to optimal. It is necessary to have check points enough to control the result of optimal value search. If there is a lack of check points it is recommended to temporarily transfer some GCP to check points (see Section 11).

   In order to record numbers of high/low order an exponent is used, for example: *"5.7e-4"*.

8. [optional] In order to use GCP measurements during adjustment, set the **Use ground control point coordinates** checkbox on.

9. [optional] In order to use projection centers data during adjustment, set the **Use projection center coordinates** checkbox on.

7.3.4. Method of initial approximation by a block scheme

Method of initial approximation calculation by a block scheme consists in using of block layout for block adjustment (see the "Aerial triangulation" User Manual).

Initial approximation by block scheme with adjustment by *bundle adjustment* method is used for a single image adjustment.

To calculate initial approximation *by block scheme* perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.

2. Click the **Adjustment** tab.

3. In the **Approximation computing method** section select the **by block scheme** method.

4. Click the **Initial approximation parameters** button. The **Initial approximation parameters** window opens.

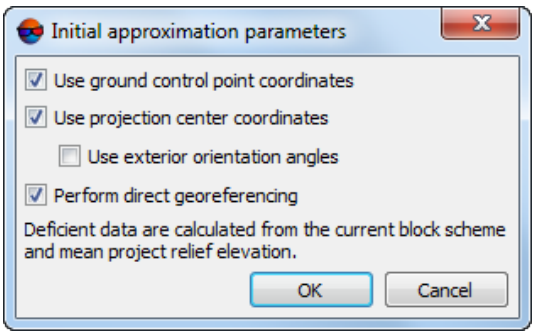


Fig. 14. The Initial approximation parameters window

5. Setup initial approximation parameters by block scheme:

   - **Use ground control point coordinates** – allows to use GCP measurements for adjustment operation;

   - **Use projection center coordinates** – if projection centers coordinates are available in catalogue of exterior orientation parameters it is possible to use them for adjustment operation;

   - **Use exterior orientation angles** – if exterior orientation angles are available in catalogue of exterior orientation parameters, the option allows to use them for adjustment operation;

   - **Perform direct georeferencing** – allows to calculate tie points coordinates using exterior orientation data. If the checkbox is set off, then X,Y coordinates of tie points are calculated using frames of images on a block scheme. For Z coordinate the system assigns average terrain height from heights difference data, specified in a project properties (see the "Project creation" User Manual).

6. Click OK. All the missing data is calculated by frames of images of current block scheme, considering average terrain height from heights difference data, specified in a project properties (see the "Project creation" User Manual).

7.3.5. Independent stereopairs method

Independent stereopairs method consists in preliminary creation of single independent models by stereopairs, and further joining them into common block and orientation of the block in geodetic coordinate system using GCP.

Independent stereopairs method is used to enhance accuracy of adjustment results, obtained during calculation of initial approximation, in order to detect smaller errors and, in case of satisfying results, for final adjustment.

For adjustment using the *independent stereopairs method* perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.

2. Click the **Adjustment** tab.

3. In the **Adjustment method** section select the **independent stereopairs** method.

4. Click the **Adjustment parameters** button. The **Independent stereopairs adjustment parameters** window opens.

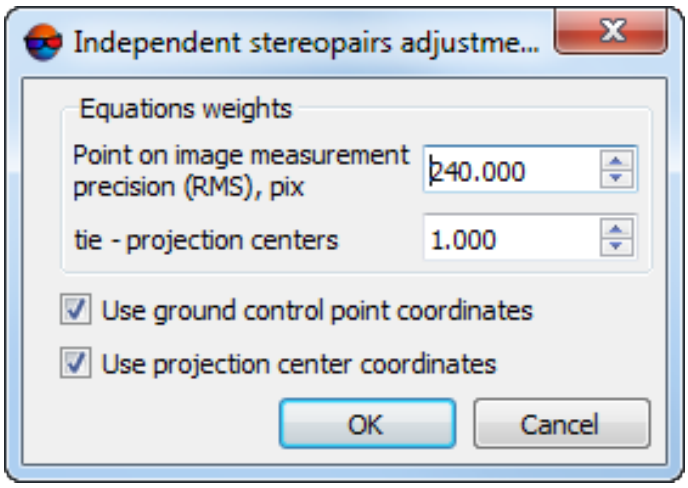


Fig. 15. The Independent stereopairs adjustment parameters window

5. [optional] In the **Equation weights** fields input the values of weights.

Considerable change of equation weights values leads to reducing of actual adjustment accuracy. There is some optimal value, at which the accuracy is maximal. In most cases the weight value of 1 is near to optimal. It is necessary to have check points enough to control the result of optimal value search. If there is a lack of check points it is recommended to temporarily transfer some GCP to check points (see Section 11).

In order to record numbers of high/low order an exponent is used, for example: *"5.7e-4"*.

6. [optional] In order to use GCP measurements during adjustment, set the **Use ground control point coordinates** checkbox on.

7. [optional] In order to use projection centers data during adjustment, set the **Use projection center coordinates** checkbox on.

7.3.6. Bundle adjustment method

Bundle adjustment method is used for final adjustment. When using the bundle adjustment method aerial triangulation and adjustment are performed for all images at once.

For adjustment by *bundle adjustment method* it is not necessary to have images triple overlap available.

The system provides possibility to perform adjustment of a single image by bundle adjustment method with initial approximation by a block scheme. To do this it is necessary to have at least three GCP available in the image. Besides, it is necessary to set the **Use exterior orientation angles** checkbox off in the **Bundle adjustment parameters** and **Initial approximation parameters** windows, and set the **Perform direct georeferencing** checkbox off in the **Initial approximation parameters** window.

For adjustment of block images using the *Bundle adjustment method* perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.

2. Click the **Adjustment** tab.

3. In the **Adjustment method** section select the **bundle adjustment** method.

4. Click the **Adjustment parameters** button. The **Bundle adjustment parameters** window opens.

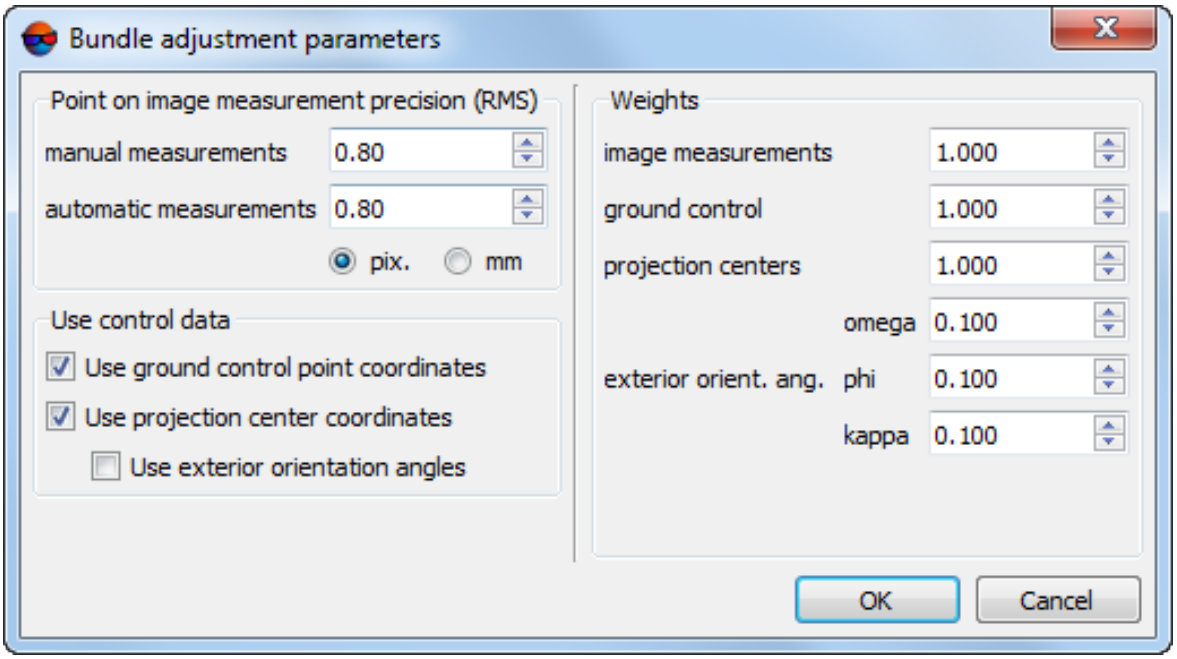


Fig. 16. The Bundle adjustment parameters window

5. In the **Point on image measurement precision (RMS)** section specify accuracy for **manual measurements** and **automatic measurements** of points coordinates on images in **pix** or **mm**.

   Accuracy of points coordinates measurements depends on photographic material quality (“grain”, blur, image deformations, not considered in camera parameters, including geometric distortions of scanner), terrain type and human factor (accuracy of measurements performed by operator).

   If step of image scanning corresponds to its quality and points are correctly recognized, measurements accuracy value lies within 0.5–1.0 of a pixel size.

6. In the **Weights** section define weights for the following data:

- weights of **image measurements**;
- **ground control points** – weight of GCP coordinates;

Input value of GCP weight is equivalent to multiplying of accuracy value of GCP coordinates taken from **Catalogue of ground control points** by 1/ W, where W – is a weight value. If GCP weight value is more than 1, then binding of triangulation network to GCP coordinates is strong, if the weight values are less than 1, the binding is weak (see the "Aerial triangulation" User Manual).

- **projection centers** – input field for weight of projection centers coordinates. Accuracy of projection centers coordinates are setup in the **Catalogue of exterior orientation parameters** (see the "Aerial triangulation" User Manual);
- **exterior orient. ang. (omega, phi, kappa)** – input field for weight of exterior orientation angles. Accuracy of exterior orientation angles are setup in the **Catalogue of exterior orientation parameters** (see the "Aerial triangulation" User Manual).

7. [optional] In order to use GCP measurements for adjustment by default, the **Use ground control point coordinates** checkbox is set on. Set the checkbox off and the system will not use the data for adjustment.
8. [optional] In order to use projection centers coordinates for adjustment by default, the **Use projection center coordinates** checkbox is set on. Set the checkbox off and the system will not use the data for adjustment.
9. [optional] In order to use exterior orientation angles for adjustment by default, the **Use exterior orientation angles** checkbox is set on. Set the checkbox off and the system will not use the data for adjustment.
10. Click OK to complete parameters setup.

7.3.7. Bundle adjustment with self-calibration

Method of bundle adjustment with self-calibration is used if a project contains not full set of camera parameters (for example, there are no all necessary passport data of camera), or if it is necessary to clarify camera parameters (see the "Aerial triangulation" User Manual).

Self-calibration of camera parameters – is automatic calculation of camera parameters (corrections to principal point coordinates and focal length, distortion coefficients) during adjustment operation.

Self-calibration of camera parameters is performed only during the bundle adjustment. When execute adjustment using other methods, specified corrections to camera parameters are considered but not optimized.

If interior orientation is done incorrectly due to absence of some camera data or due to incorrectly specified camera data, so self-calibration of camera parameters on adjustment step using georeference data (GCP, exterior orientation parameters) allows to calculate missing data.

For self-calibration of camera parameters at least focal length is required, specified in the **Camera** window (see the *Interior orientation* chapter in the "Aerial triangulation" User Manual)

For self-calibration of camera parameters it is recommended to use georeference data (GCP and/or exterior orientation parameters) during block adjustment. The system also allows to use self-calibration in free model, that allows to analyze systematic errors and make decision whether it is necessary to go on with self-calibration.

Self-calibration results depend on a set of initial camera data, block configuration (position of block images and strips, which depends on flight scheme), availability of georeference data (GCP, exterior orientation parameters) and tie points measurements. Description of all self-calibration features are out of scope of the User Manual (see appropriate references about the subject).

To use self-calibration of camera parameters during adjustment operation perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.
2. Click the **Adjustment** tab.
3. Set the **Perform self-calibration** checkbox on in the **Camera parameters self-calibration** section.
4. Click the **Self-calibration parameters** button. The **Camera parameters self-calibration** window opens.

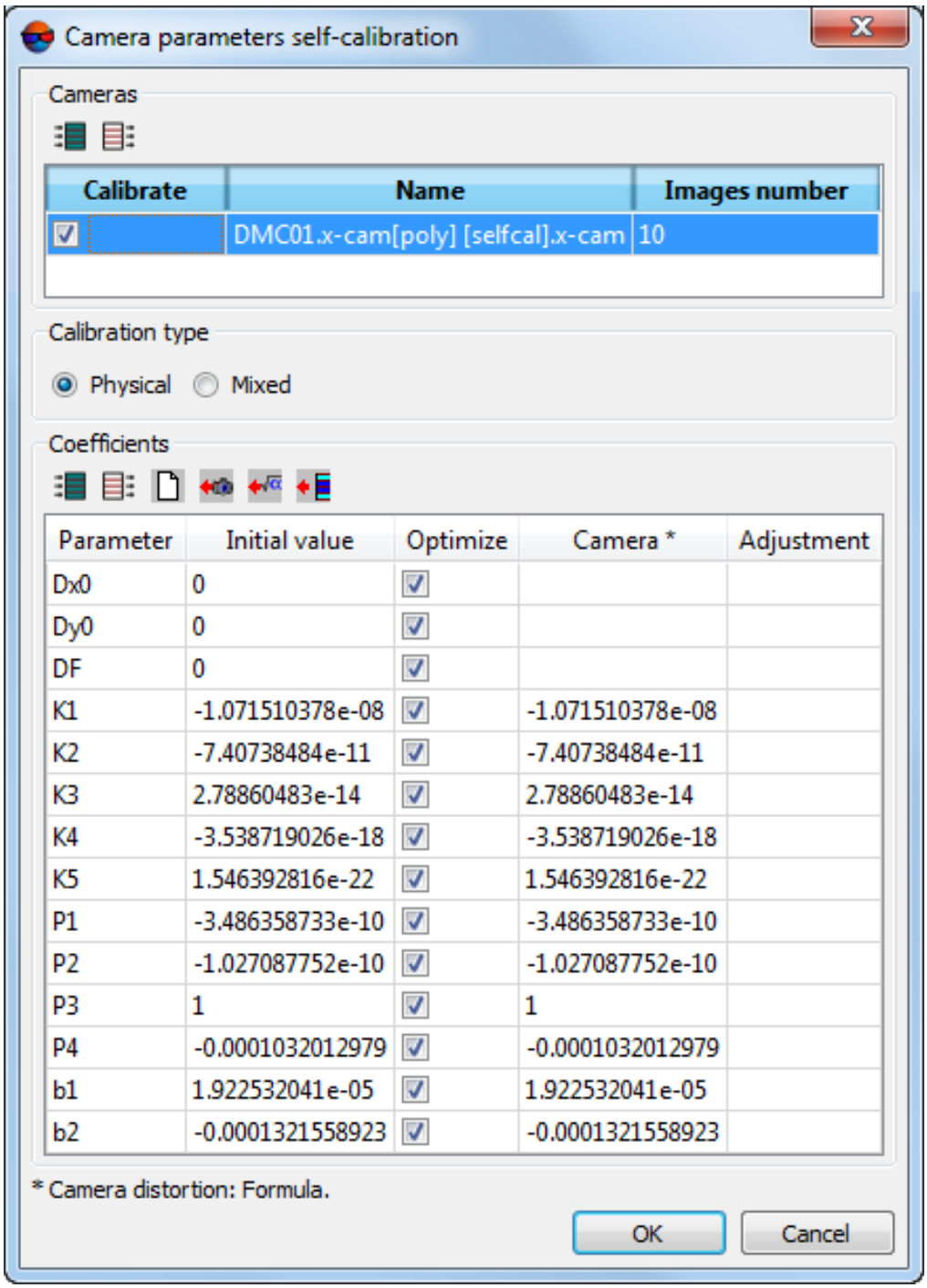


Fig. 17. The Camera parameters self-calibration window

5. In the **Cameras** table mark cameras which are needed to be calibrated.

6. Select the **Calibration type**: **Physical** or **Mixed**.

For self-calibration of a camera having a focal plane shutter, it is recommended to use **Mixed** self-calibration.

7. Click the button to copy coefficients from the camera passport.

8. In the **Coefficients** table define initial values of camera parameters in the **Initial value** column and select parameters for optimization in the **Optimize** column (see Section 7.3.7).

9. Click OK to complete setup of camera self-calibration parameters.

10. Setup the adjustment parameters in the **Parameters** window.

11. Click the **Compute** button. When the adjustment procedure is completed estimate the adjustment accuracy and results of camera self-calibration shown in the **Adjustment** column of the **Camera parameters self-calibration** window. In case of satisfying results pass to the next step, otherwise, change initial values and/or a set of optimization parameters and adjust the block once more.

12. Click the **Save** button to save the adjustment results.

13. Choose **Orientation › Manage cameras** (**Ctrl+Alt+I**). The **Manage project cameras** window opens.

14. In the **Project cameras** list select new calibrated camera (cameras) `[selfcal].xcam` and assign it (them) to project images. Click the **Execute** button (see the "Aerial triangulation" User Manual). Click OK.

15. Choose **Orientation › Interior orientation › Calculate interior orientation**.

16. Click the button **Settings** on the **Adjustment** toolbar. Block will be adjusted considering new results of interior orientation.

In certain cases, since some **coefficients** can be dependent, it is impossible to calculate corrections to them (during camera calibration, before performing adjustment). In such cases, some of these coefficients can be automatically excluded from the calibration process (but not from the adjustment process) i.e. during data processing, the **initial value** will be used, without introducing corrections. An appropriate info message is to be displayed in the progress bar (see the "Loading progress window" section in the "General information" User Manual).

7.3.8. Parameters of camera self-calibration

The system allows to setup parameters of camera self-calibration. The **Camera parameters self-calibration** window is used to do this. The window also allows to specify initial values of parameters and define a set of parameters for optimization during adjustment operation.

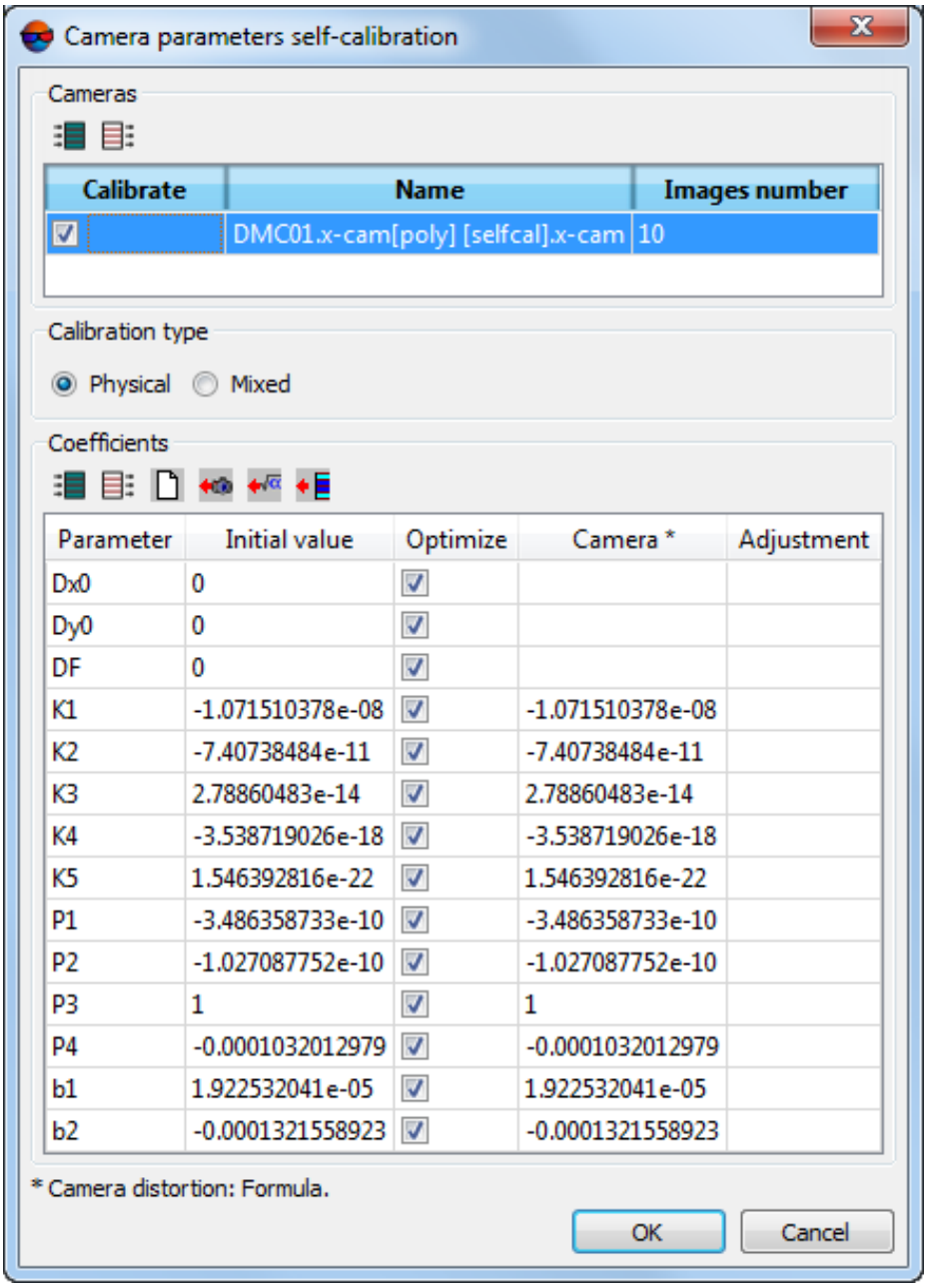


Fig. 18. The Camera parameters self-calibration window

The **Camera parameters self-calibration** window contains the following tables:

- the **Cameras** is used to select cameras to be calibrated;
- the **Coefficients** is used to define initial parameters values, to select optimization parameters and perform analysis of parameters values calculated during adjustment;
- a toolbar that contains buttons used for work with data of the **Coefficients** table.

The **Calibration type** section allows to choose method of camera self-calibration coefficients calculation. In most cases it is recommended to choose the **Physical** calibration type.

For self-calibration of a camera having a focal plane shutter, it is recommended to use **Mixed** self-calibration.

During the camera self-calibration, **physical** or **mixed** calibration will be used in any case, regardless of what type of distortion was selected in the **Camera** window (see "Project cameras management" in the "Aerial triangulation" User Manual).

The source tabular data on distortion from the camera passport, which was specified at the stage of entering camera parameters, will be approximated for use according to the selected equation.

The **Coefficients** table contains the following columns:

- **Parameter** – list of the following camera parameters:
  - `Dx0` – offset from the principal point by X in mm;
  - `Dy0` – offset from the principal point by Y in mm;
  - `DF` – deviation from focal length value in mm;
  - `K1`, `K2`, `K3`, `K4`, `K5` – coefficients of radial distortion;
  - `P1`, `P2`, `P3`, `P4` – coefficients of tangential distortion;
  - `b1`, `b2` – coefficients of image deformation.
- **Initial value** – initial parameters values, that are used during self-calibration in adjustment operation;
- **Optimize** – selection of parameters for optimization during adjustment operation considering initial values.To enable parameter optimization, set the appropriate checkbox;
- **Camera** – initial data of camera, specified on interior orientation step in the **Camera** window (see the "Project cameras management" chapter in the "Aerial triangulation" User manual);

  On step of initial orientation during input of camera parameters, user specifies absolute values of principal point coordinates and focal length, that is why data for `Dx0`, `Dy0`, `DF` deviations are absent in the **Camera** column.

- **Adjustment** – results of self-calibration (after adjustment operation), calculated as a result of adjustment of selected for optimization parameters.

The **Camera parameters self-calibration** window contains the following buttons used to work with the data of the **Coefficients** table:

- – allows to select all parameters for optimization;
- – allows to cancel optimization of all parameters;
- – allows to setup “0” value for all parameters in the **Initial value** column;
- – allows to copy all parameters values from the **Cameras** column to the **Initial value** column;
- – allows to copy all parameters values from the **Adjustment** column to the **Initial value** column;
- – allows to copy parameter value from selected cell to the **Initial value** column.

By default during the very first self-calibration of project cameras is used the following scenario:

- all project cameras are selected in the **Cameras** table for self-calibration;
- initial camera parameters are used as initial values of each camera parameters for self-calibration (i.e. The data from the `Cameras` column to the **Initial value** column are copied automatically);

  Since absolute values of principal point coordinates and focal length are specified at camera parameters input, then in the **Initial value** column for `Dx0`, `Dy0`, `DF` deviations the “0” value is shown.

- the following parameters are selected for optimization during adjustment procedure: `DF` to calculate focal length deviation from its initial value, and `K1`, `K2`, `K3` to calculate distortion coefficient.

Approximation of distortion coefficients

During the camera self-calibration, **physical** or **mixed** calibration will be used in any case, regardless of what type of distortion was selected in the **Camera** window.

If the type of distortion, other than **physical** or **mixed** (**Radial**, **4 directions +**, **4 directions “X”** or **8 directions**), was initially specified for the camera, then, when entering the characteristics of this camera, the respective tabular distortion data are to be entered in the **Camera** window.

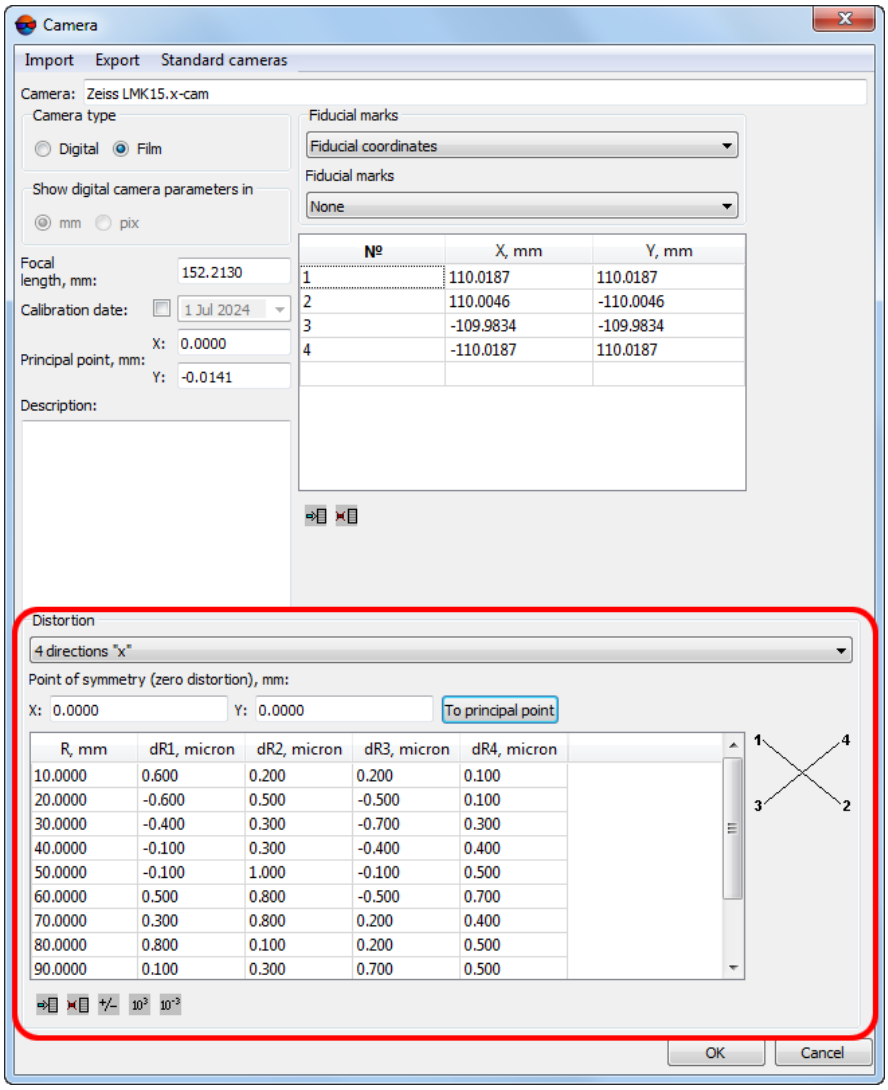


Fig. 19. Initial table data of distortion from camera passport, defined in the Camera window during input of camera parameters step

For such a camera, distortion coefficients are displayed in the **Camera** column of the **Coefficients** table in the **Camera parameters self-calibration** window (see above). These coefficients are obtained as a result of source tabular distortion data approximation using the following equation:

$$x_{corr} = x - k_1 x r^2 - k_2 x r^4 - k_3 x r^6 - k_4 x r^8 - k_5 x r^{10} - \left(1 + P_3 r^2 + P_4 r^4\right) \cdot \left(P_1 \left(r^2 + 2x^2\right) + 2P_2 xy\right) - b_1 x - b_2 y$$
$$y_{corr} = y - k_1 y r^2 - k_2 y r^4 - k_3 y r^6 - k_4 y r^8 - k_5 y r^{10} - \left(1 + P_3 r^2 + P_4 r^4\right) \cdot \left(P_2 \left(r^2 + 2y^2\right) + 2P_1 xy\right) - a_1 x - a_2 y$$
$$r^2 = x^2 + y^2$$

where:

x, y – coordinates of symmetry point (zero distortion) in mm;

k1, k2, k3, k4, k5 – coefficients of radial distortion;

`p1`, `p2`, `p3`, `p4` – coefficients of tangential distortion;

`a1`, `a2`, `b1`, `b2` – image deformation coefficients.

Some coefficients (`a1`, `a2`) can be dependent, so it is impossible to calculate corrections to them (during camera calibration, before performing adjustment). These coefficients are excluded from the calibration process (but not from the adjustment process) automatically, i.e. during data processing, the initial coefficient value will be used, without introducing corrections. An appropriate info message is to be displayed in the progress bar (see the "Loading progress window" section in the "General information" User Manual).

As a result of approximation by formula that uses least-squares method, the distortion coefficients and root-mean-square error (RMS) of approximation are calculated.

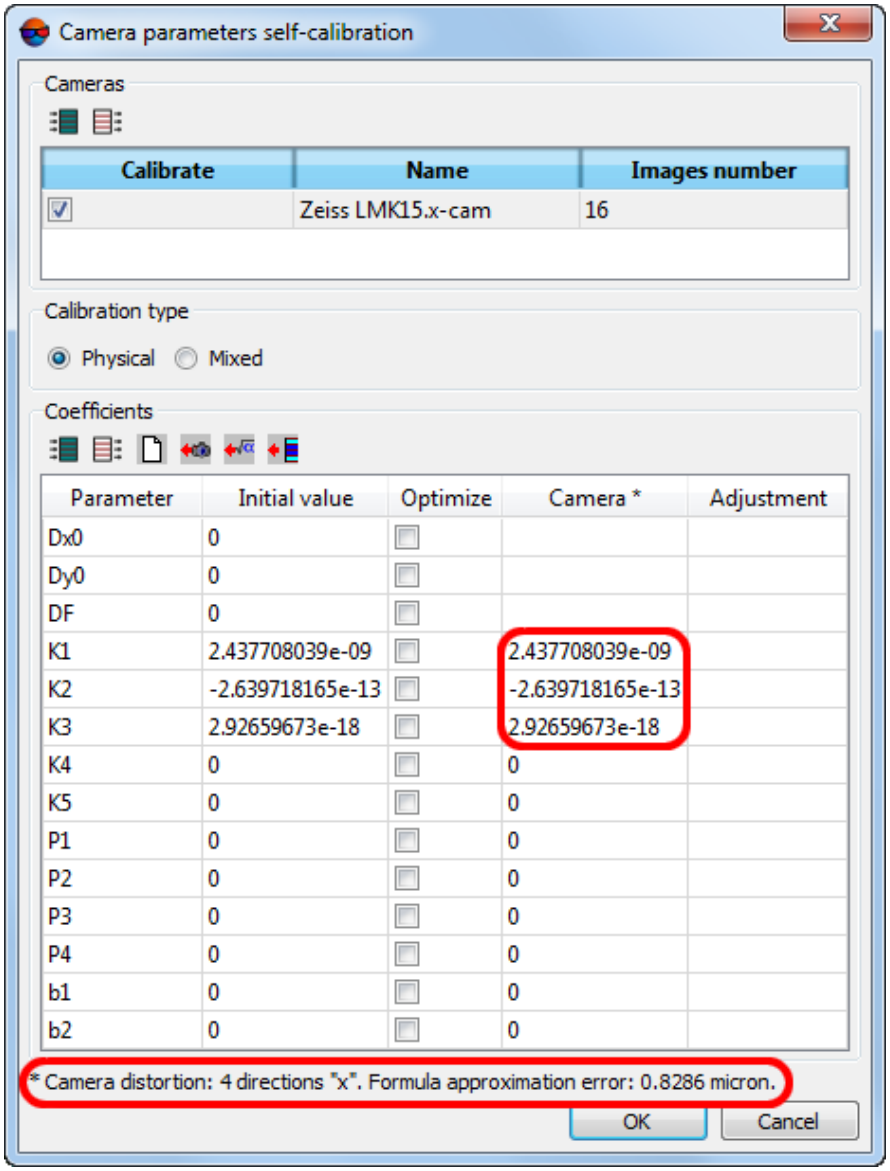


Fig. 20. Distortion coefficients K1, K2, K3 calculated as a result of approximation by formula, and distortion error

After performing the adjustment ( ) in terms of the given parameters of self-calibration and data saving ( ), a new calibrated camera with a name containing the suffix `[[selfcal]`, with a mixed or physical type of distortion, is added to the list of project cameras, depending on the user-specified self-calibration parameters.

7.3.9. Compensation of systematic errors

There is a possibility to calculate systematic errors of block measurements automatically and compensate them during block adjustment.

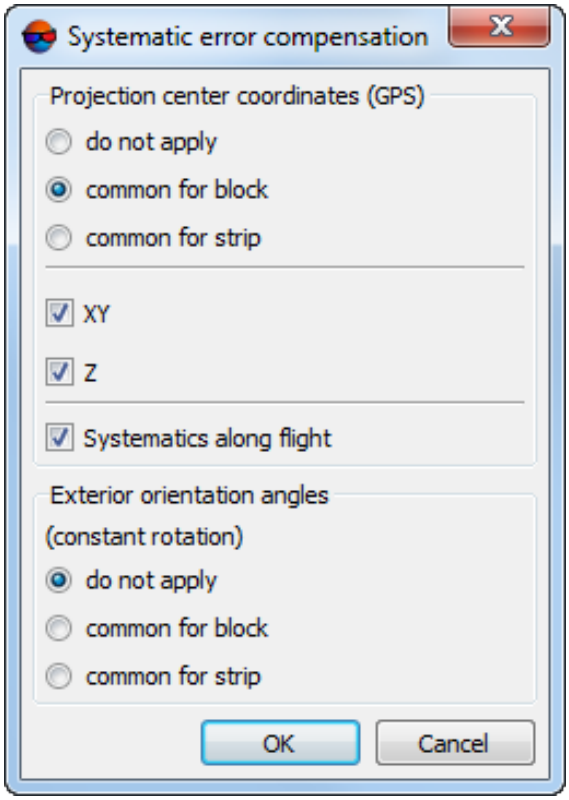


Fig. 21. The Systematic error compensation window

If a survey was performed using GPS equipment, that was used to define projection centers coordinates, it is possible to calculate corrections to these coordinates during adjustment. To do this set the appropriate checkbox in the **Projection center coordinates (GPS)** section. In general the system considers errors, added by GPS device during flight along a strip, that is why it is recommended to choose the **common for strip** option.

Specify **Compensation type** option, to define a type of compensation to be applied to coordinates of projection centers (GPS):

- **do not apply**;
- **common for block** – is used to consider systematic errors in each block;

- **common for strip** – is used to consider errors obtained due to work of GPS device (recommended option).

It is possible to include calculated values of GPS systematic error to adjustment report.

The **XY** and **Z** checkboxes allow to specify coordinates to which corrections will be added.

For UAS data, significant systematic errors in the coordinates of the projection centers take place, that arise due to the lack of distinct synchronization between the clocks of the GPS receiver and camera. When processing such data, don't clear the default **Systematics along flight** checkbox (except for data processing cases definitely without such errors).

The **Exterior orientation angles (constant rotation)** section is used to specify a type of corrections applied to exterior orientation angles of images, if they are specified in a project and are considered for adjustment:

- **do not apply**;
- **common for block** – is used to consider systematic errors in each block;
- **common for strip** – is used to consider errors obtained due to work of GPS device (recommended option).

Corrections in the **Exterior orientation angles (constant rotation)** section are used only for *bundle adjustment* method.

The corrections are as follows:

$$\begin{aligned} \Delta\ \omega &= A_\alpha \\ \Delta\ \phi &= A_\phi\ , \\ \Delta\ \kappa &= A_\kappa \end{aligned}$$

where A – coefficients calculated at adjustment.

7.3.10. Select subblock

The system allows to perform adjustment just for a part of a block (subblock).

To perform subblock adjustment perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.
2. Click the **Adjustment** tab.
3. Set the **Adjust subblock** checkbox.

4. Click the **Select subblock** button. The **Select subblock** window opens.

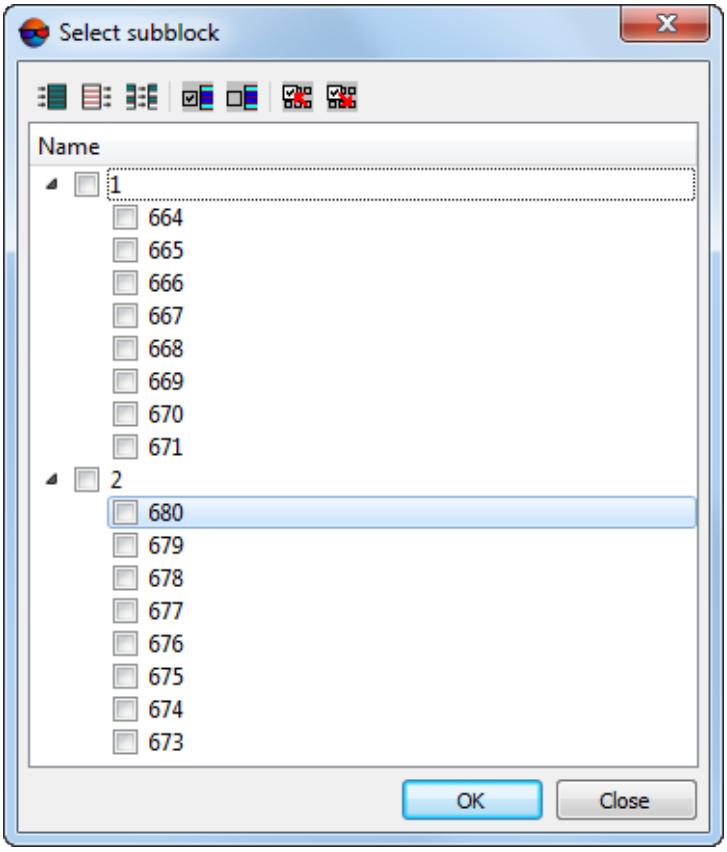


Fig. 22. The Select subblock window

5. Select images to define a subblock content, using the following tools of images selection:

- – allows to select all images in the list;
- – allows to deselect all images in the list;
- – allows to inverts images selection;
- – allows to select highlighted images;
- – allows to unselect highlighted images;
- – allows to select the images that are highlighted on block scheme in 2D window;
- – allows to highlight on block scheme in 2D window the images selected in the list.

6. Click OK.

7.4. The “Report” tab

The **Report** tab is intended for setup of adjustment results display, as well as for setup parameters of errors display on a block scheme.

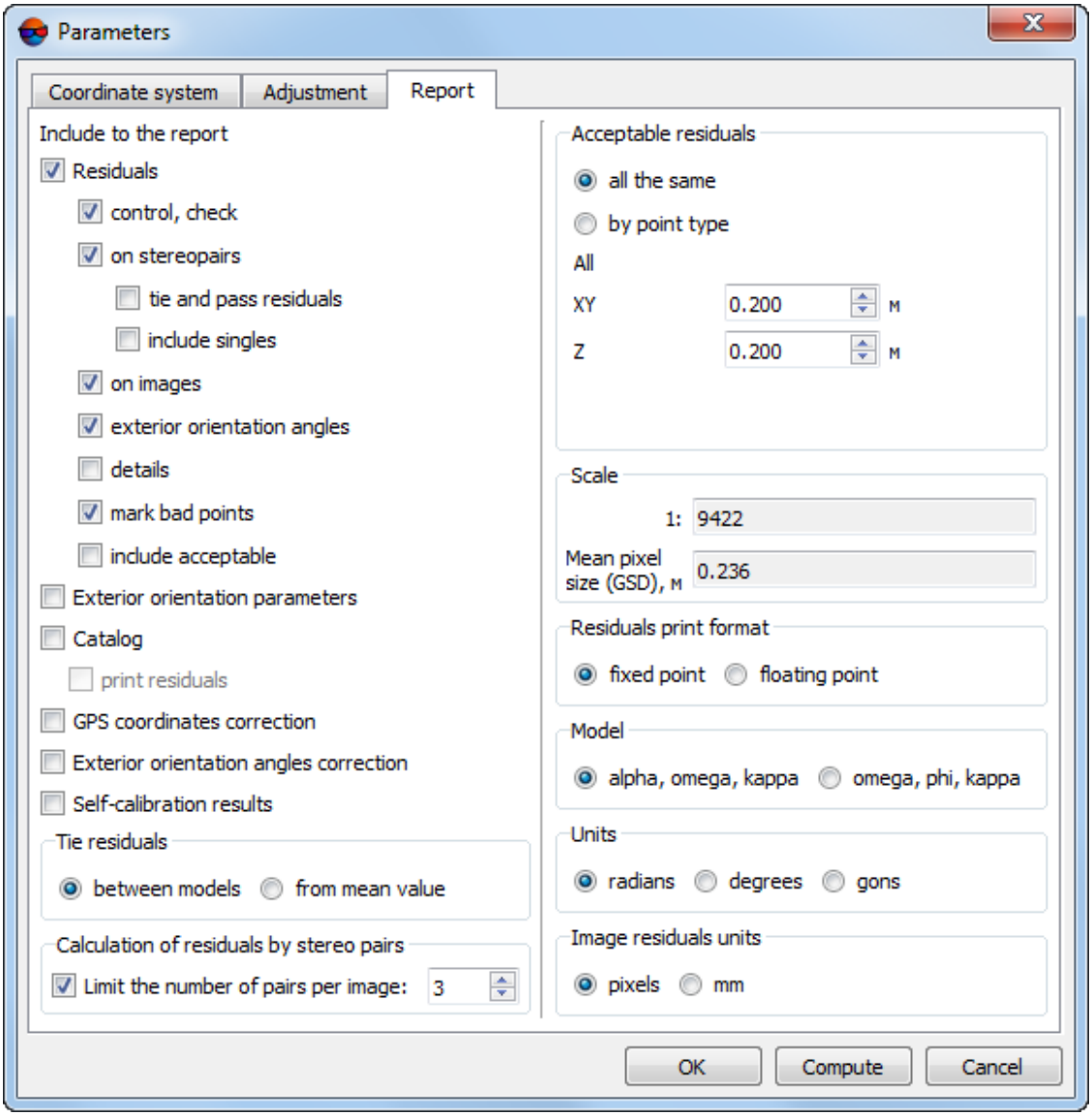


Fig. 23. The Settings window

The **Report** tab contains the following parameters:

1. The parameters group **Include to the report** is used to setup adjustment results display in report:

   - **Residuals** – in report display the following types of residuals :

- **control, check** – adjustment residuals on GCP and check points;
- **on stereopairs** – adjustment residuals on points, which coordinates are changed at least on a single stereopair:
  - **tie and pass residuals** – tie residuals, calculated between strips and inside strips;
  - **include singles** – adjustment residuals on points, which coordinates are measured on a single stereopair.

  It is recommended to set the **include singles** checkbox on only when it is necessary to calculate the **from mean value** residuals in the **Tie residuals** section.

  During adjustment by *independent stereopairs* method or by *independent strips* method residuals on points measured just on a single stereopair equals to zero.

  During *bundle adjustment* residuals on points measured just on a single stereopair were less then 0.1 of vertical parallax value on terrain.

- **on images** – adjustment residuals on images (in mm or pixel);
- **exterior orientation angles** – residuals on angle exterior orientation parameters, only if the angles are specified in a project were used during adjustment;
- **details** – is used to display detailed information about residuals (including images and stereopairs numbers);
- **mark bad points** – is used to display adjustment residuals, which exceed specified threshold;
- **include acceptable** – is used to display all adjustment residuals, including those that fall within specified threshold.

- **Exterior orientation parameters** – is used to display exterior orientation parameters of each image in a report;
- **Catalog** – is used to display in a report geodetic coordinates of all points calculated during adjustment. When the **print residuals** checkbox is set, the points catalogue shows residuals on GCP and check points;
- **GPS coordinates correction** – is used to display GPS corrections to projection centers in a report;

  It is recommended to set the **GPS coordinates correction** checkbox when projection centers are used as GCP, and systematic error in GCP coordinates is defined.

- **Exterior orientation angles correction** – is used to display corrections to angular exterior orientation parameters in a report;

  It is recommended to set the **Exterior orientation angles correction** checkbox on when exterior orientation angles are used during adjustment, and to define systematic errors of exterior orientation angles.

- **Self-calibration results** – is used to display self-calibration results of camera parameters in a report.

  It is recommended to set the **Self-calibration results** checkbox on only for bundle adjustment operation. In this case it is recommended to set the **Perform self-calibration** checkbox on in the **Camera parameters self-calibration** section.

2. The **Tie residuals** section is used to select method of calculation tie residuals between stereopairs:

   - **between models** – tie residuals from difference of the same point positions, calculated on each stereopair;

   - **from mean value** – tie residuals from difference of the same point position, calculated on each stereopair and its mean adjusted position.

3. The **Calculation of residuals by stereopairs** section allows to **limit the number of pairs per image** during calculations.

   The number of potential stereopairs for each image (in particular, taking into account inter-strip pairs) can be quite large.

   Processing of all possible stereopairs may affect negatively the system performance and lead to an unreasonable increase in the size of the adjustment report.

   As a rule, for correct calculation of tie residuals between stereopairs, it is enough to process about 3-4 stereopairs for each of the images.

4. The **Acceptable residuals** section allows to specify residuals threshold of block adjustment:

   It is necessary to specify acceptable residuals of block adjustment in units of project coordinate system.

   - **all the same** – the same thresholds for all kinds of points. In the **All** section there are the **XY** and **Z** fields used to input residual threshold;

   - **by point type** – different threshold for each types of points. In the the **Ground control**, **Check**, **Projection centers**, **Tie**, **Targeted**, **Tie-projection centers** fields there are the **XY** and **Z** fields used to input threshold for each type of residuals.

5. The **Scale** section allows to specify survey scale, used for residuals re-calculation from image scale to block scale and vice versa.

   A value of survey scale is calculated automatically during adjustment, or is specified manually.

   Mean pixel size on terrain (ground sample distance) calculated after adjustment, is specified in the **Mean pixel size (GSD)** input field.

6. The **Residuals print format** section is used to specify format of numeric values of residuals in a report:

   - **fixed point** – residuals display with accuracy up to 3 *decimal points*;
   - **floating point** – residuals display with accuracy up to 3 *significant digits*.

7. The **Model** section is used to specify format of exterior orientation angles system (see Appendix A):

   - **Alpha, omega, kappa** – are used in Russian coordinate systems;
   - **omega, phi, kappa** – are used in international coordinate system (see Appendix A).

8. The **Units** section is used to setup format of angles measurements units:

   - **radians**;
   - **degrees**;
   - **gons** – plane angle measurement unit that equals to 1/100 of flat right angle measurement unit, and full angle is 400 gons.

9. The **Image residuals units** section is used to setup format of angles measurements units:

   - **pixels**;
   - **mm**.

8. Adjustment of scanner blocks

At that preliminary parameters setup is required. A set of the parameters depends on method of scanner data processing:

- *Rigorous method* – allows to process remote sensing products, that include metadata files with interior and exterior orientation parameters. Rigorous algorithm of images processing provides accuracy that is about image resolution (by RMS on check

points). It allows to use minimal number of ground control points and to obtain more accurate results during calculation of exterior orientation parameters;

- *RPC-method* – allows to process remote sensing products, that include metadata RPC-files (for example, IKONOS, QuickBird, OrbView-3). With RPC-coefficients available you can use fewer amount of GCP to obtain satisfying results of photogrammetric processing;

- *Generic method* – the method uses parallel-perspective model or *Direct Linear Transformation* (DLT) algorithm, that allows to process *any* scanner images (including IRS, LandSat, etc.). However, it requires more GCP per stereopair (10 GCP is recommended, 6 at least) as compared with rigorous algorithm;

- *Import of adjustment* – for setup of adjustment parameters the system provides dedicated mode for adjustment of scanner block, acquired by ADS 40/80/100 digital sensor.

8.1. Workflow of scanner block adjustment

The **Parameters** window is used to setup parameters of adjustment accuracy, select adjustment method procedure, as well as to setup a content of adjustment results report.

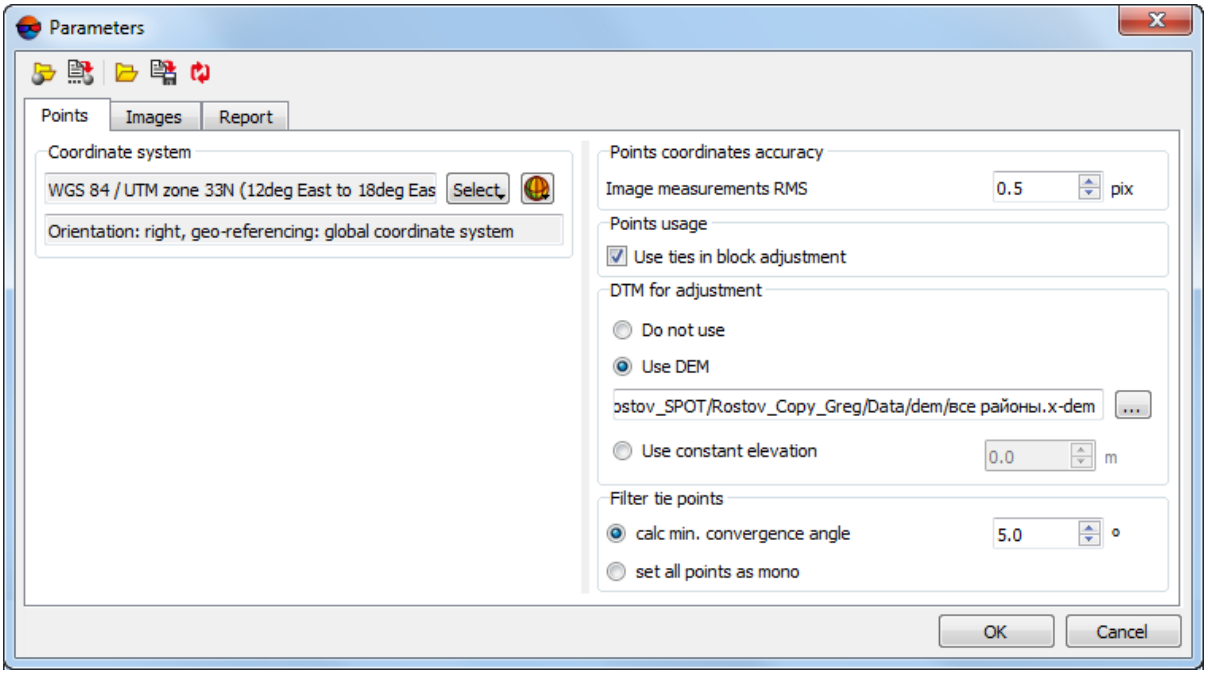


Fig. 24. The Parameters window

A toolbar in the upper part of the **Parameters** window is intended to save/load parameters settings on all tabs of the window and contains the following buttons:

- – allows to load parameters settings saved previously to active profile resources;

- – allows to save all parameters settings to `*.x-ini` file located in the *ProjOption* project folder in active profile resources;
- – allows to load parameters settings from *<project name>.options.x-solver-s.* file located in a folder of *Windows* file system;
- – allows to save parameters settings to *<project name>.options.x-solver-s* file located in a folder of *Windows*file system;
- – allows to restore default parameters settings.

In order to adjust scanner images block perform the following actions:

1. Click the button of the **Block Adjustment** toolbar. The **Parameters** window opens;
2. On the **Points** tab select coordinate system and setup parameters of adjustment accuracy and points use;
3. On the **Images** tab choose method and parameters of adjustment;
4. Click the **Apply to all** button to apply adjustment settings to all project images or click the **Apply** button to apply all adjustment settings to a single image selected in the table;
5. On the **Report** tab specify values of the following acceptable residuals:
   - for control, check and tie points;
   - acceptable residuals (RMS) of grouping of images, acquired from the same orbit (if there was any grouping).

   Setup display parameters of adjustment results in a report;
6. Click OK to close the **Parameters** window;
7. Click the button to start the adjustment operation;
8. To display and analysis of adjustment results in the report window click the button of the **Block Adjustment** toolbar;
9. In case of satisfactory results of adjustment click the button of the **Block Adjustment** toolbar to save adjustment data. Proceed to step of project processing (DEM creation, vectorization, orthomosaic creation).

   Otherwise (in case of poor result), correct errors appeared on a step of data collection for aerial triangulation (see also the “Aerial triangulation” User Manual) and/or

change settings of adjustment parameters in the **Parameters** window and start the adjustment operation once more.

8.2. The “Points” tab

The **Points** tab of the **Parameters** window allows to choose project coordinate system, and to setup parameters of calculation accuracy of points coordinates.

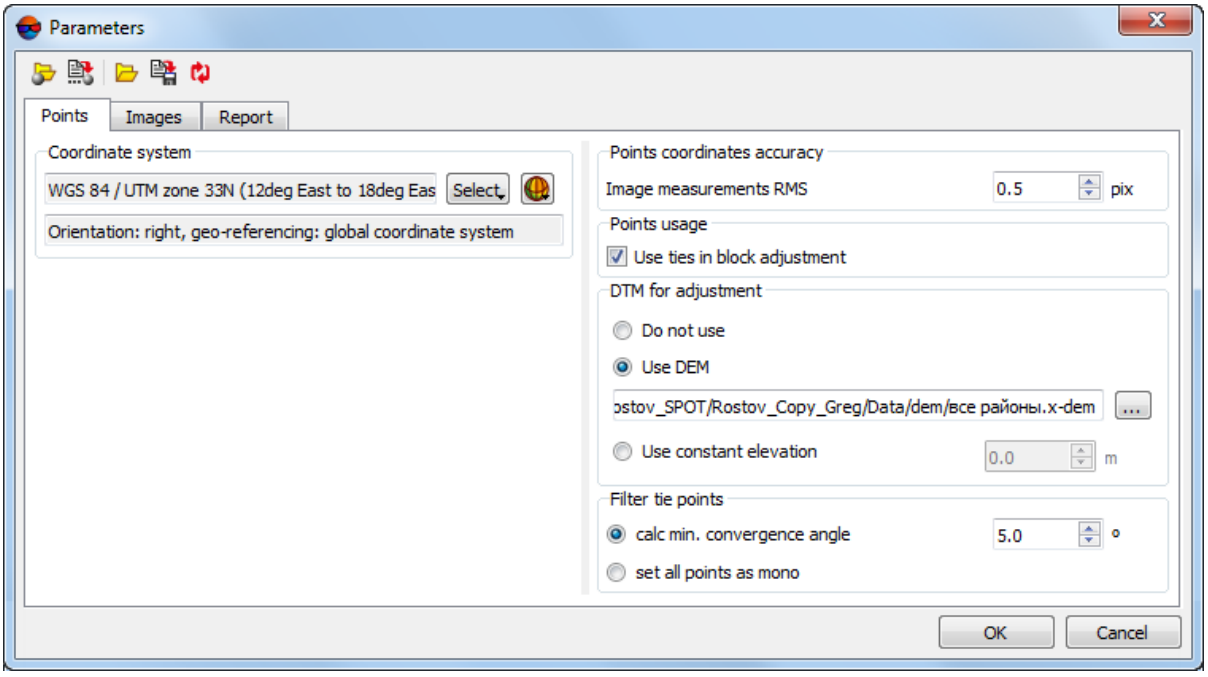


Fig. 25. Parameters of adjustment

The **Points** tab contains the following parameters:

- the **Coordinate system** section is used to display project coordinate system. The **Select...** button allows to change current coordinate system of a project (detailed information about selection of coordinate system see in “Creating new project” chapter of “Project creation” User Manual);
- the **Points coordinates accuracy** section is used to specify **Image measurements RMS** (pix.) – a priori accuracy of pixel measurements of GCP and tie points on images (if the latter were used for adjustment);
- the **Points usage** section is used to setup using/excluding tie points in/from adjustment operation (the checkbox is set by default).

Only metadata will be used for relative orientation of images. However, the computation of tie point errors will be carried out anyway and displayed in the adjustment report

- the **DTM for adjustment** section is used to consider DEM or specified constant elevation in adjustment:
  - **Do not use** – to perform adjustment without DEM;
  - **Use DEM** – allows to use DEM from file (from active profile resources);
  - **Use constant elevation** – allows to use constant elevation of relief instead of DEM.

    It is recommended to perform adjustment of projects with images of flat terrain.

- the **Filter tie points** section allows to set the ties rejection parameters:
  - [optional] **calculate minimal convergence angle** to exclude from adjustment tie points with convergence angle less than given value. To do this specify the minimum acceptable convergence angle in degrees.

    During the adjustment, the points having convergence angles lesser than minimum acceptable convergence angle will be processed as *tie points excluded from adjustment*, but type of these points will not be changed to *Excluded* (see the “Points filter” chapter of the “Aerial triangulation” User Manual).

    Set the **Include the list of points rejected by convergence angle** checkbox in the **Report** tab to add the list of tie points excluded by convergence angle into the report.

  - [optional] **set all points as mono**.

8.3. The “Images” tab

8.3.1. Parameters of scanner images adjustment

The **Images** tab is used to specify adjustment method of scanner images block, as well as to setup the adjustment parameters.

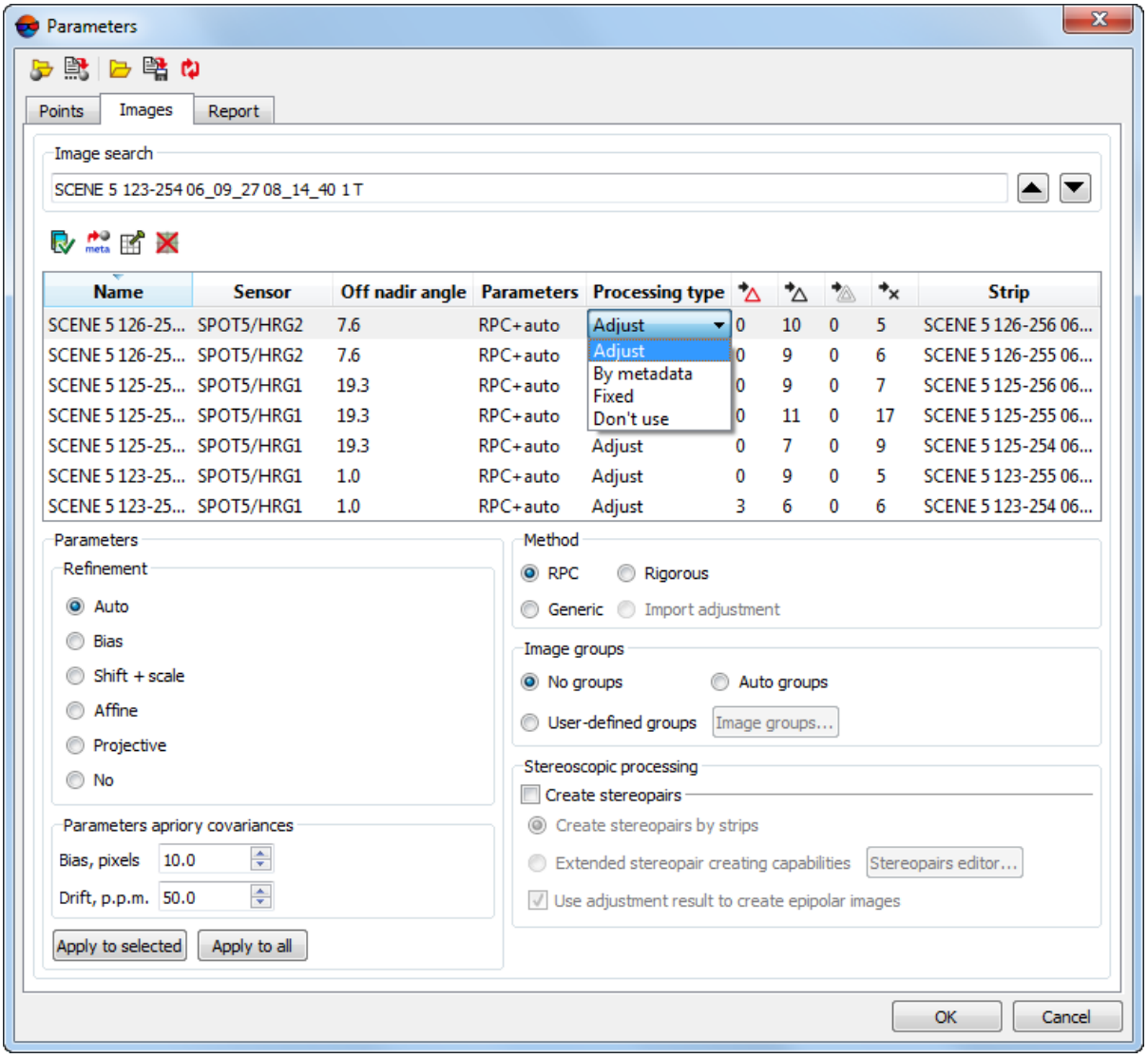


Fig. 26. The Images tab

The **Images** tab consists of the following sections:

- the **Image search** section allows to perform the search in the table containing images. To do this perform the following:
  - type the search query in the input field;
  - [optional] click the ▲ button to set the search direction;
  - [optional] click the ▼ button to set the search direction.
- the table containing the following images data:
  - **Name**;

- **Sensor**;
- **Off-nadir angle**;
- The adjustment **parameters**, which set depends on selected method of images processing;
- **Processing type** of separate image chosen by user:
  - **Adjust** the image according to the specified settings;
  - **By metadata** – adjust the image according to metadata only;
  - **Fixed** – save the adjustment results for the given image (do not change them during next adjustment iterations);

    The results of image adjustment will remain the same at further adjustment iterations. Saving the adjustment results for the group of images can be useful, for example, when new images are to be added to the image block and changes to the “old” part of the block are unwanted.

  - **Don’t use** this image in the adjustment.

  To change the image **processing type**, **double left-click** the desired cell in the appropriate column and choose the item you need in the drop-down menu.

  To change the image **processing type** for several images at once, select the needed images in the table and click the appropriate button in the toolbar above the table.
- – the number of GC points on the image;
- – the number of control points on the image;
- – the number of excluded GC points on the image;
- – the number of tie points on the image;
- **Strip**.

The system allows to sort images by the column headings of the table and multiple selection of pictures, using **Ctrl** and **Shift** keys.

- the **Parameters** section allows to setup adjustment parameters, which set depends on selected method of images processing (see the appropriate chapters below).

If the **Import adjustment** option is selected, there are no parameters, since all exterior orientation elements are imported from ADS 40/80/100 data, acquired after preliminary processing and adjustment of images block in dedicated software like *ORIMA*.

The **Apply** and **Apply to all** buttons allows to apply setup parameters to images, selected in the **Images** table, or to all images of a block correspondingly.

- the **Method** section allows to select adjustment method:
  - **Rigorous** method – see Section 8.3.2;
  - **RPC** – method which uses RPC-coefficients – see Section 8.3.3;
  - **Generic** method – see Section 8.3.4;
  - **Import adjustment** – import of exterior orientation parameters from metadata.

    The **Import adjustment** parameter is used only for ADS 40/80/100 projects.

- the **Image groups** section allows to setup **images groups, acquired from the same orbit**:

  If groups of images are available for block adjustment this allows to use less number of GCP per block (see recommendations in Section 8.7).

  - [optional] **No groups** – no image grouping;
  - [optional] For manual grouping of images that are used for adjustment procedure, select the **User-defined groups** option. Images groups are used only for images acquired from the same orbit.
  - [optional] For automatic creating of images groups by ties with automatic filtering of incorrect ties, select the **Auto groups** parameter.

    In order to display information about filtered ties in a report, select **Detailed report** option in the **Image groups** section of the **Report** tab.

- the **Stereoscopic processing** section allows to set the **Create stereopairs** checkbox to perform adjustment with stereopairs creation.
  - [optional] In order to create stereopairs from every two adjacent images of a strip, select the **Create stereopairs by strips** option.

    The **Create stereopairs by strips** parameter is used for stereoblocks only.

- [optional] In order to form stereopairs from block images manually select the **Extended stereopair creating capabilities** option and click the **Stereopairs editor...** button.

In order to calculate epipolar images using tie points, set the **Use adjustment result to create epipolar images** checkbox off. Otherwise, the system will calculate epipolar images just after adjustment, since the checkbox is set by default.

It is recommended to set the **Use adjustment result to create epipolar images** checkbox to obtain correct models on stereopairs with complicated enough geometry (at asynchronous stereo survey).

- the **Adjustment steps** section is used to perform step-by-step adjustment – successive adjustment of selected subblocks of scanner space images.

8.3.2. Rigorous method of adjustment

When perform adjustment by *rigorous* method the system considers exterior orientation parameters from images metadata, obtained from RSD provider.

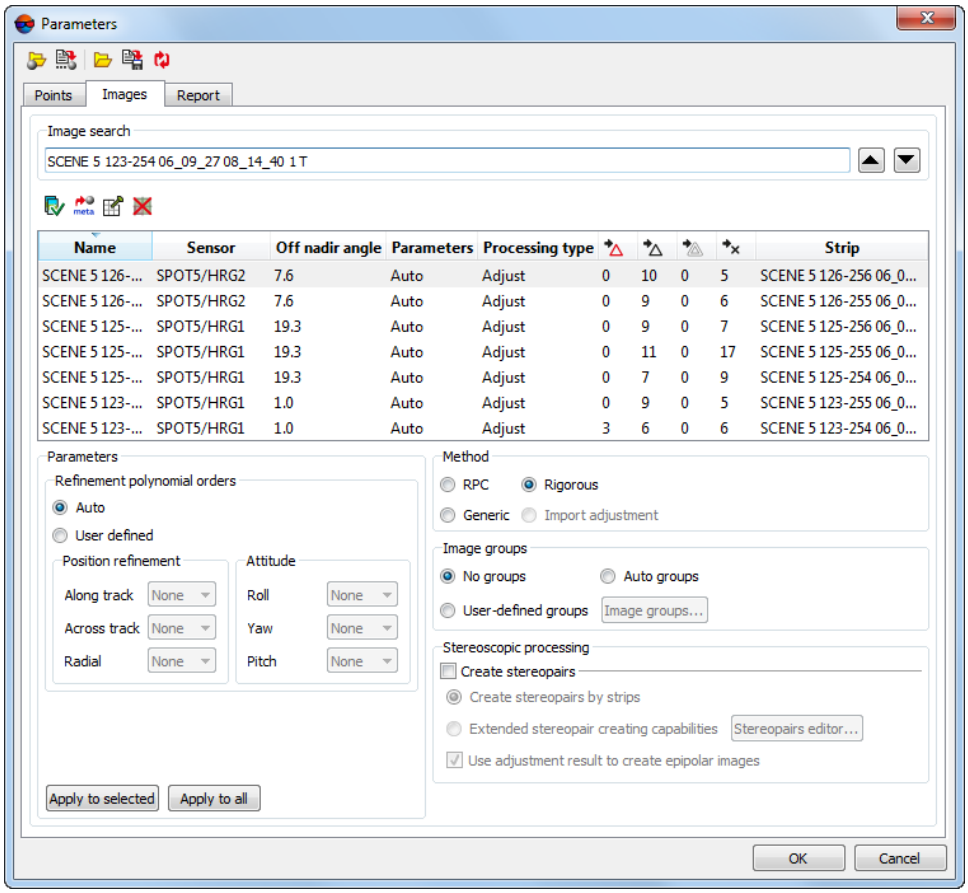


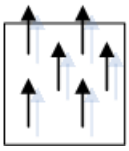
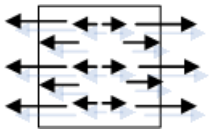
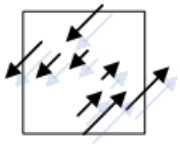
Fig. 27. Parameters of rigorous method of adjustment

During adjustment procedure the system applies corrections to linear and angular exterior orientation parameters, obtained from images metadata. The corrections are polynomials, which orders are calculated by the system automatically or are setup by user manually. The corrections are setup depending on type of exterior orientation parameters:

- for linear exterior orientation parameters – **Along track**, **Across track**, **Radial**;
- for angular exterior orientation parameters – **Roll**, **Yaw**, **Pitch**.

It is recommended to use automatic corrections applying first, and then after obtaining adjustment results (during analyzing results shown in report or analyzing residuals vectors in the Images and Stereopairs modes) it is possible to make a decision whether to setup refinement values manually for some exterior orientation parameters. In order to setup the refinement manually select the **User defined** option in the **Refinement polynomial orders** section, specify a polynomial order or set the **–** (it is set on by default) if it is necessary to not to submit a refinement.

Table 2. Interpretation of error vectors caused by inaccuracy of exterior orientation parameters

Refinement type	Direction of error vector
Along track / Pitch	
Across track / Roll	
Radial	
Yaw	

8.3.3. RPC method

When perform adjustment by *RPC method* the system uses RPC coefficients from metadata, obtained from RSD provider.

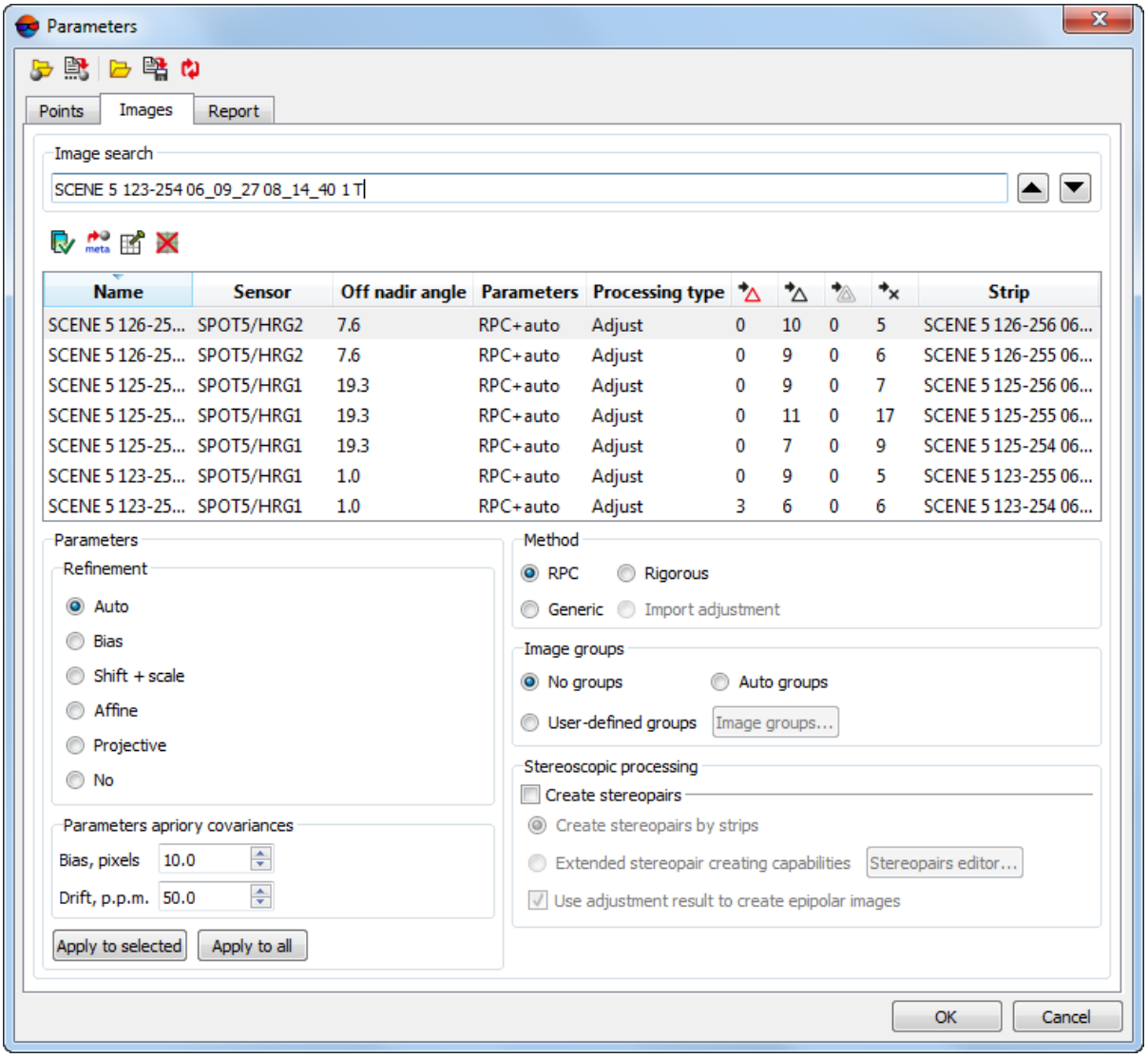


Fig. 28. Parameters of images adjustment using RPC coefficients

The **Refinement** section allows to select one of the following types of corrections, which are applied to RPC coefficients during adjustment:

- **Auto** – a correction type is defined automatically by number of GCP and tie points;
- **Bias** – constant correction will be applied to RPC;
- **Shift+scale** – two constant corrections will be applied to RPC;
- **Affine** – affine correction will be applied to RPC;
- **Projective** – projective correction will be applied to RPC;
- **None** – no correction will be applied to initial RPC; this parameters is used for example, to check correctness of GCP or project coordinate system.

Parameters of the **Parameters a priory covariances** section allow to specify accuracy of initial RPC and accuracy of coordinate system specifying (for example, in case of approximation of local coordinate system with unknown parameters using topocentric horizontal coordinate system).

The **Parameters a priory covariances** section contains the following parameters:

- **Bias (pixels)** – a priori estimate of the accuracy of determining the linear shift of images along the X, Y, and Z axes, caused by the movement of the sensor along its trajectory, expressed in pixels of the image;
- **Drift (p.p.m.)** – an a priori assessment of the accuracy in determining angular displacements and distortions of images caused by significant angles of deviation of the camera from the nadir (a dimensionless coefficient is used, expressed in parts per million).

Parameters a priory covariances are specified by the user based on available information about the sensor, the obtained adjustment results, and the geometric characteristics of images.

The system provides opportunity to use DEM for adjustment by RPC-method to increase adjustment accuracy. There are the following recommendations concerning use of DEM during adjustment:

1. It is recommended to use DEM in projects with relatively smooth relief, i.e. with smooth elevation difference. Otherwise, sharp elevation difference in tie point area or artefact on DEM lead to incorrect data.
2. It is not recommended to use DEM if there are a lot of triangulation points, since it results in significant slowing down of adjustment procedure.
3. For stable work it is recommended to decrease the **Bias** parameter value on the **Parameters apriory covariances** section in relation to default value.

Optimal value could be selected experimentally and could be both 1 and up to 0.01.

8.3.4. Generic adjustment method

Generic method supposes using affine, and parallel-perspective model or DLT (Direct Linear Transformation) algorithm and allows to process *any* scanner images (including IRS, LandSat, etc.). However, at that it is necessary to have more GCP per stereopair as compared to *rigorous* algorithm (at least 4 GCP; recommended 10 GCP, see Section 8.7).

For orthomosaic processing (for example, to process images acquired by SPOT-5 with 2A processing level, see more details in description of satellite system) **only** generic adjustment method is used.

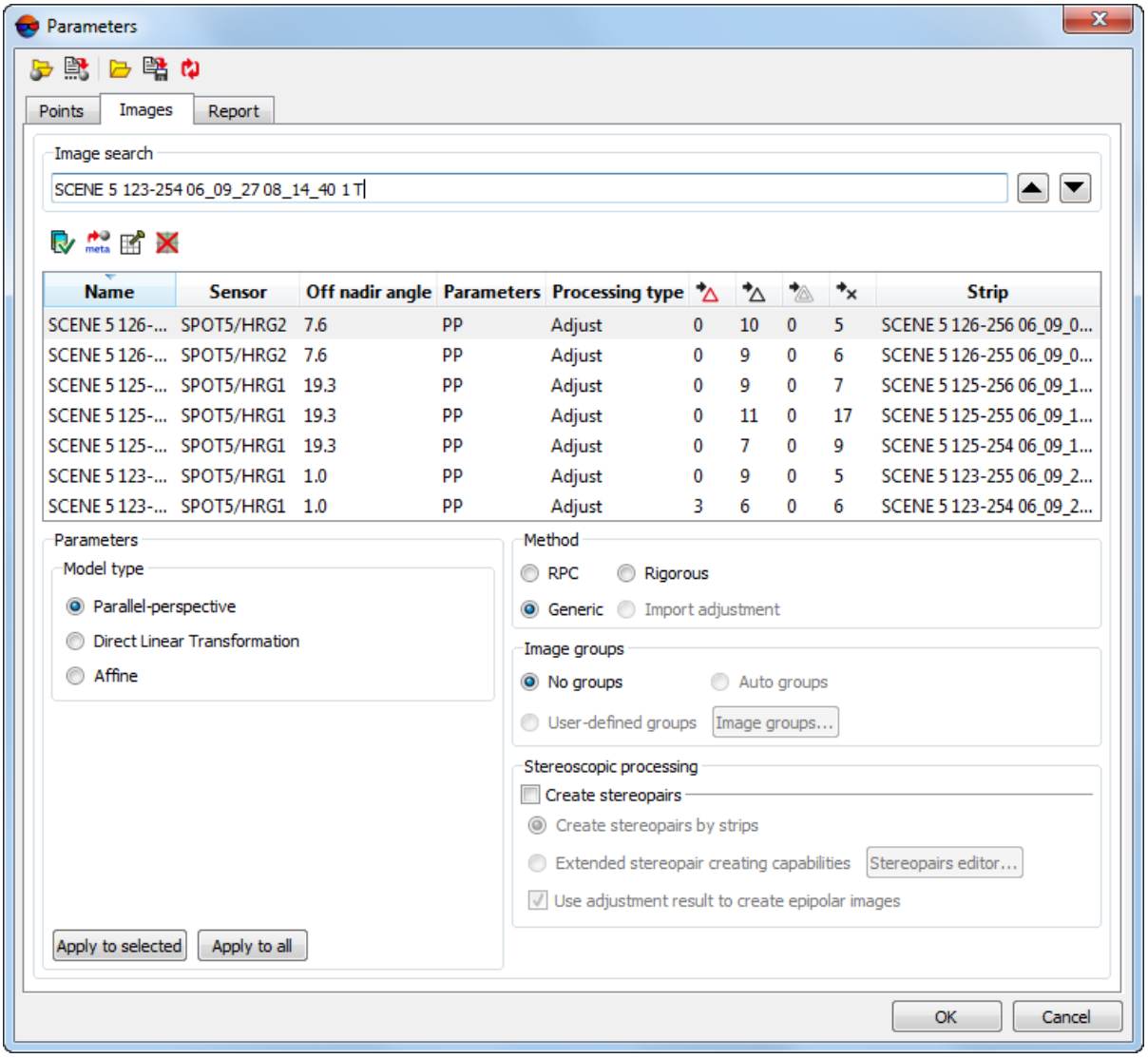


Fig. 29. Parameters of generic method of images adjustment

The **Model type** section is used to select one of the following model types depending on a number of used GCP:

- **Parallel-perspective** – at least 7 GCP;
- **Direct Linear Transformation (DLT)** – at least 6 GCP;
- **Affine** – at least 4 GCP.

The more the number of GCP the better the accuracy of adjustment results, however, wherever possible it is recommended to use **Rigorous** or **RPC**-method, which provide better accuracy as compared to generic method results.

8.3.5. Manual creation of stereopairs

The system provides opportunity to form stereopairs from block images manually during adjustment of images block.

Stereopairs forming is performed in the **Stereopair editor** window, which allows to create stereopairs automatically from adjacent images of each strip. In addition, it is also possible to set stereopairs formed by non-adjacent images of a strip and to add interstrip stereopairs. Besides, manual stereopairs forming allows to build epipoles for selected images.

To open a **Stereopair editor** window perform the following:

1. Click the button of the **Block Adjustment** toolbar. The **Parameters** window opens;

2. Click the **Images** tab;

3. In **Stereoscopic processing** section set the **Create stereopairs** checkbox on. Select the **Extended stereopair creating capabilities** option;

4. Click the **Stereopair editor** button. The **Stereopair editor** window opens.

Manual creation of stereopairs is performed in those cases when it is necessary to form stereopair from images with small overlap area or with intersection angle in range from 25 to 40 degrees.

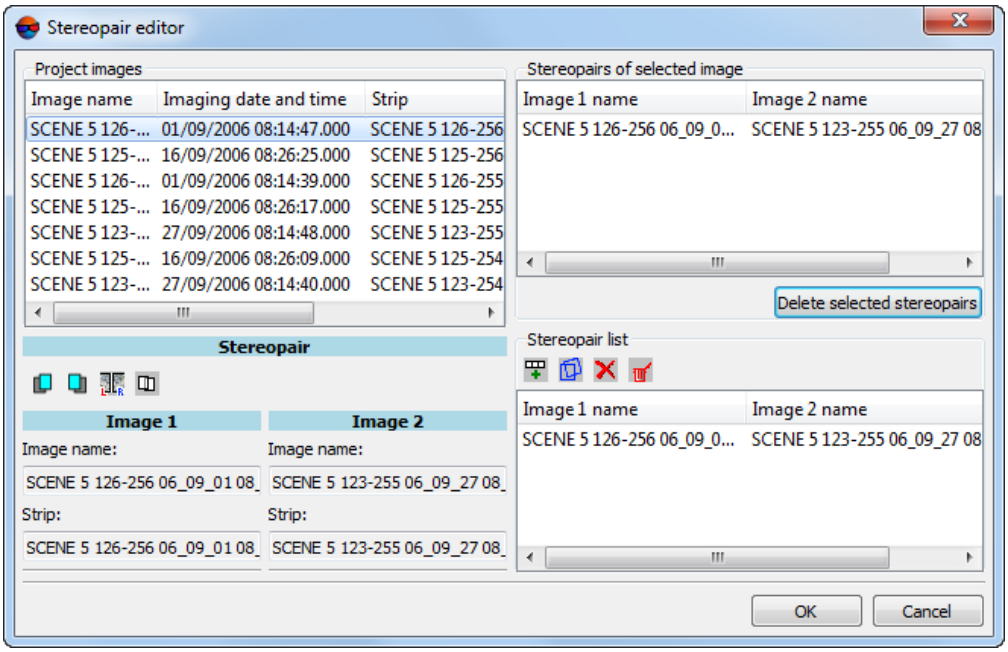


Fig. 30. The Stereopair editor window

The **Stereopair editor** window contains the following sections:

- **Project images** – a table with all block images with specified imaging date and time, strip number and whether the image is included to a stereopair;
- **Stereopair** – allows to select two images from the **Project images** table to form a stereopair from them;
- **Stereopairs of selected image** – a table displaying all defined stereopairs, to which is included the image, selected from the **Project images** table;
- **Stereopairs list** – list of all formed stereopairs.

To edit a list of created stereopairs use (delete selected) and (delete all) buttons, located near the **Stereopairs of selected image** and **Stereopairs list** tables.

The system provides the following methods of stereopairs generation:

- Creating by strips – automatic stereopairs creation from adjacent images of each strip;
- Create stereopairs manually;
- Creating by overlaps – allows to form stereopairs by parameters of images overlap in a strip.

To perform automatic stereopairs creation from adjacent images of each strip click the button. The stereopairs would be created in automatic mode.

To form stereopairs manually perform the following actions:

1. Select left image from the **Project images** table and click the button in the **Stereopair** section, to add the first image;
2. Select right image from the **Project images** table and click the button in the **Stereopair** section, to add the second image;
3. Click the button to confirm and add stereopair to the **Stereopairs list** table. Otherwise click the button (to clear the **Stereopair** section);
4. [optional] Repeat these actions to create more stereopairs.

To form stereopairs by parameters of images overlap in a strip, perform the following actions:

1. Click the button. The **Find stereopairs by overlaps** window opens.

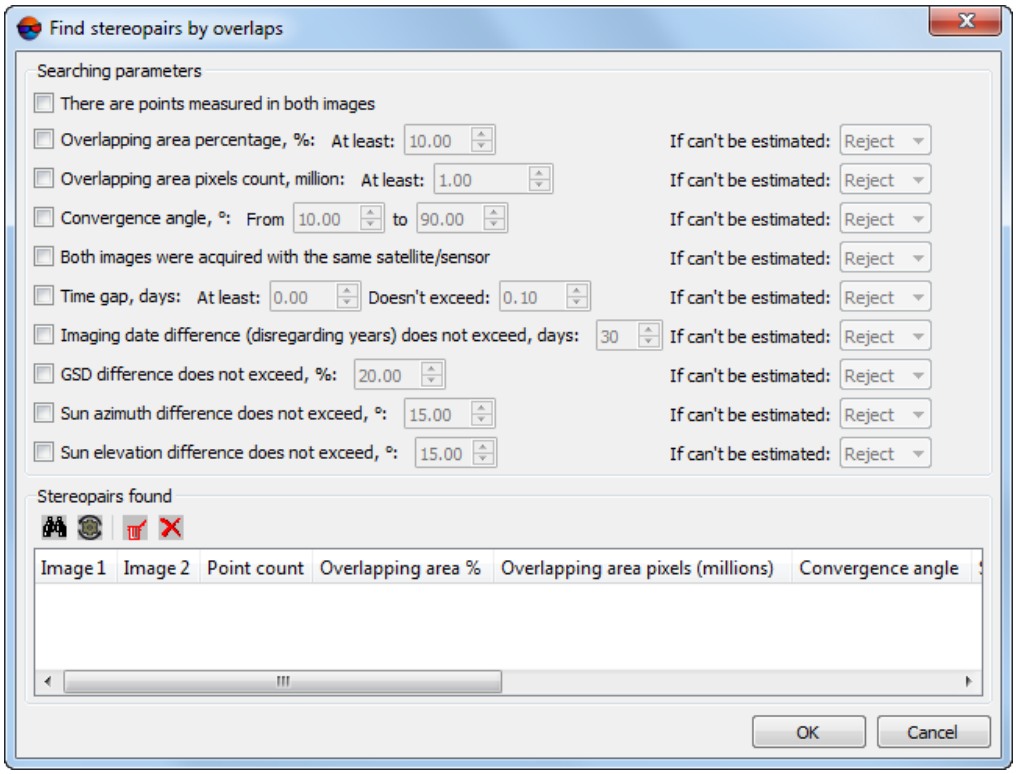


Fig. 31. Parameters of stereopairs search by overlaps

2. Set one or multiple checkboxes to search for maximal number of stereopairs using selected parameters depending on the following tasks:

   - to check correctness of stereopair forming from different time images or from images acquired from different sensors set the **There are points measured on both images**;

   - to form stereopairs in order to create digital elevation model set the **Overlapping area percentage** checkbox on and specify overlap value in the **At least** field in percent and/or set the **Convergence angle** checkbox on and specify a range of angle values to the **from..to** fields in degrees;

   - to limit stereopairs forming using number of pixels, hitting into images overlap, set the **Overlapping area pixels count** checkbox on and specify the **At least** value in millions of pixels;

   - to form stereopairs just from images acquired by the same sensors, set the **Both images were acquired with the same satellite/sensor** checkbox on;

   - to search for images using restriction by survey data, set the **Time gap** checkbox on and specify a number of days in the **At least...** and **Doesn't exc...days** fields;

- to search for images taken in the specified season, set the **Imaging date difference (disregarding years)** checkbox on and specify a number of days in the **Doesn't exceed...days** field;
- to limit stereopairs forming using value of spatial resolution, set the **GSD difference should not exceed** checkbox on and specify the value in the field in percent.
- The **Sun azimuth difference does not exceed** checkbox sets maximum difference of Sun position angles at the moment of taking each of the two images of a stereopair;
- The **Sun elevation difference does not exceed** checkbox sets maximum difference of the Sun elevation over the horizon at the moment of taking each of the two images of a stereopair;

In case when some of the parameters cannot be calculated or recognized on stereopairs (the **If can't be estimated** option is used) the system provides the following two ways. Select the **Reject** in drop-down list to ignore stereopairs with mismatched parameters, or select **Accept** to create stereopairs anyway. To reset all the parameters click the (reset parameters) button.

3. Click the button to find stereopairs. In **Stereopairs found** table all the stereopairs that match the search criteria are displayed as well as their properties.

To edit a list of created stereopairs use (delete selected) and (delete all) buttons.

4. Click OK to return to the **Stereopair editor** window. The stereopairs from **Stereopairs found** table would be automatically added to the **Stereopairs list** in **Stereopair editor** window.

OK button in **Stereopair editor** window allows to create stereopairs for their further use in the adjustment procedure. Otherwise click the **Cancel** button.

8.3.6. Groups of images acquired from the same orbit

The system provides opportunity to create group of images, acquired from the same orbit, that allows to use less GCP for scanner block adjustment. It is enough to use 4 GCP per *each image group*. The system provides possibility to create images groups automatically (by sensor type, survey time and off-nadir angle), as well as possibility to select images and make groups manually.

For automatic creation of images groups select the **Auto groups** option. The system automatically selects images acquired by the same sensor, and with the same survey time and off-nadir angle.

To create groups from images acquired from the same orbit perform the following actions:

1. Analyze images suitability to be grouped: compare them by survey time (time difference should not exceed 1 minute) and check images joint in overlap areas in the **Aerial triangulation** module.

2. Measure tie points coordinates in overlap areas in order to group images. For correct images grouping it is recommended to measure at least 2-3 points coordinates in each images overlap.

   When it is impossible to create images groups, it is necessary to increase the number of tie points, and the progress window displays the message about this error during images groups creating (after pressing the button).

   Tie points used for creating images groups cannot be involved to block adjustment.

3. Click the button on the **Adjustment** toolbar. The **Parameters** window opens.

4. On the **Images** tab set the **User-defined groups** checkbox on and click the **Set groups...** button. The **Image groups editor** window opens.

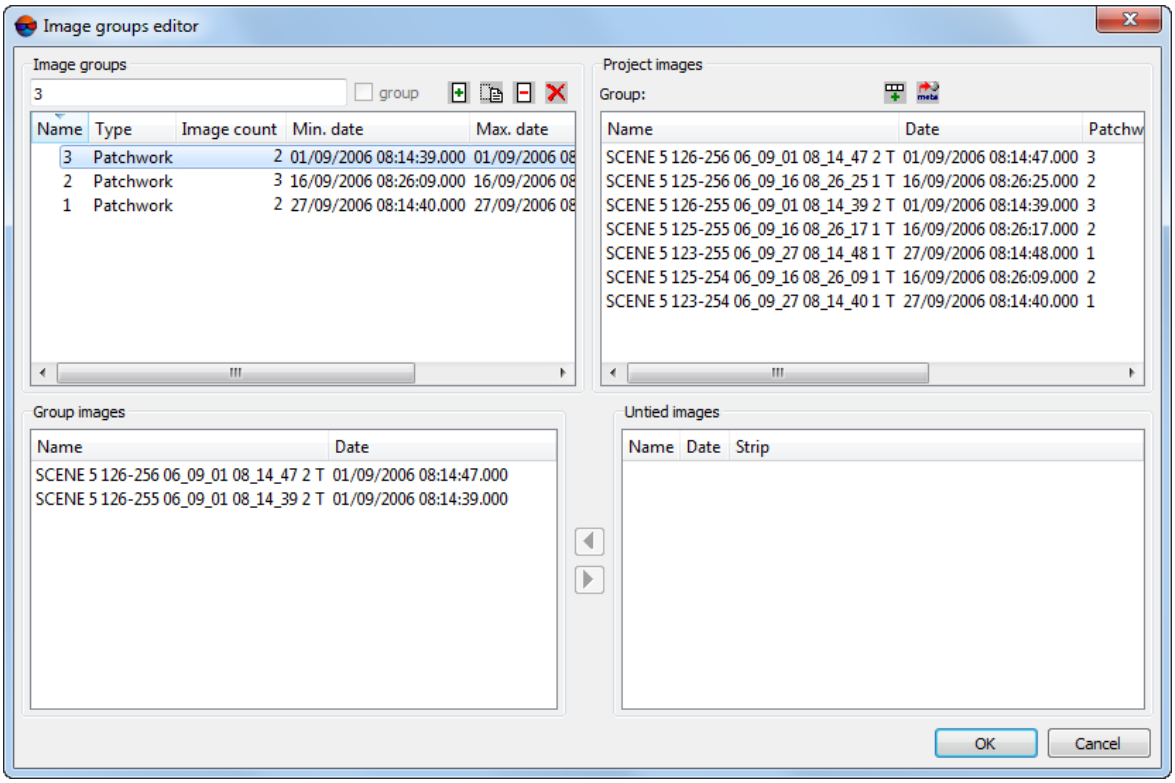


Fig. 32. The Image groups editor window

5. [optional] If it is possible to group images from each strip, click the button, to create the groups according by the project strips. In order to create images groups using metadata click the button.

To group images by strips it is necessary prior to groups creating split images into strips by orbits in the block editor.

6. Set a name of new images group in the input field, located over the **Image groups** table and click the button. A new image group will be created in the table.

7. In order to add images to created images group (to define images list to be grouped), select the appropriate images group in **Image groups** table. Use the appropriate buttons (,) to move the images between the **Group images** and **Untied images** tables.

   Statistic data about images group will be opened in a row of the **Image groups** table: number of images selected for group creation and imaging time difference of these images (minimal and maximal time, duration in seconds).

   If imaging time difference is significant (more than *one* minute) creation of images group becomes doubtful. In this case it is recommended to perform additional research of images overlap areas in the **Aerial triangulation** module (see the "Aerial triangulation" User Manual).

   In order to delete the images group – select the appropriate images group in **Image groups** table and click . The images from this group will be moved to the **Untied images** table.

   Click the button to delete all image groups.

   To rename an images group – select the appropriate images group in **Image groups** table, set a new name of images group in the input field, located over the table and click .

8. Click OK to return to the **Images** tab of the **Parameters** window. Images groups will be displayed in the **Images** table.

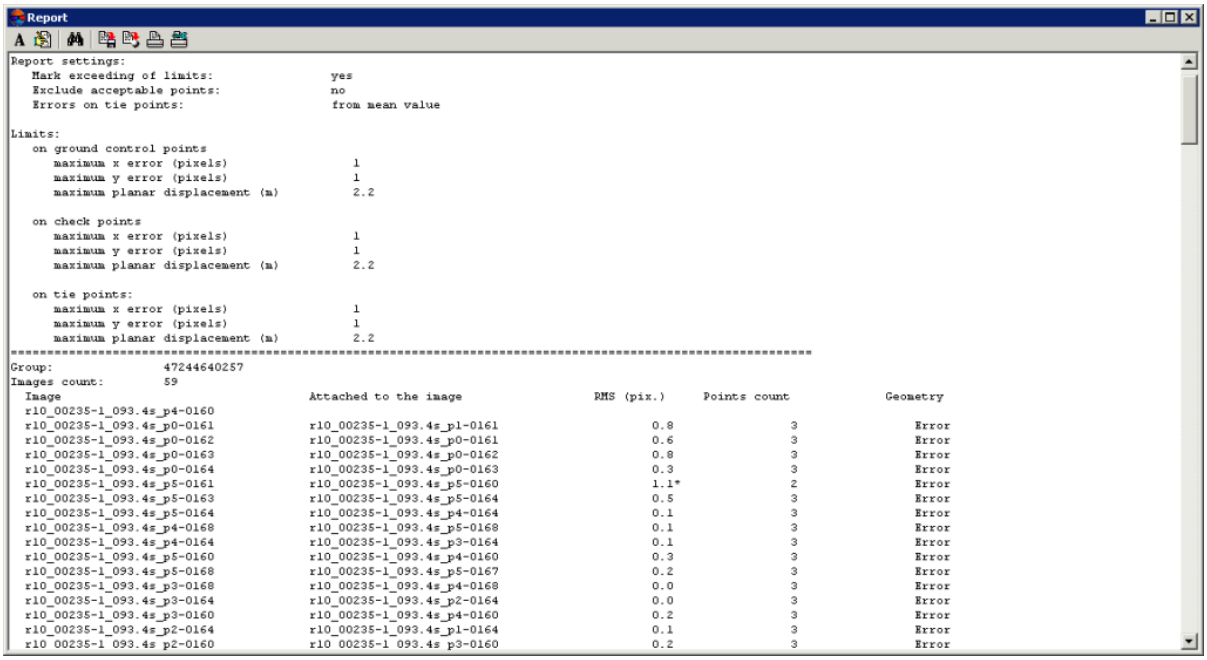
9. On the **Report** tab in the **Image groups** section setup display parameters of grouping results in a report, and specify image group join threshold.

   It is recommended to set the RMS value less than 1 pixel. For images acquired from the same orbit image group join threshold should not exceed 0.01 pixel.

10. Click the **Compute** button.

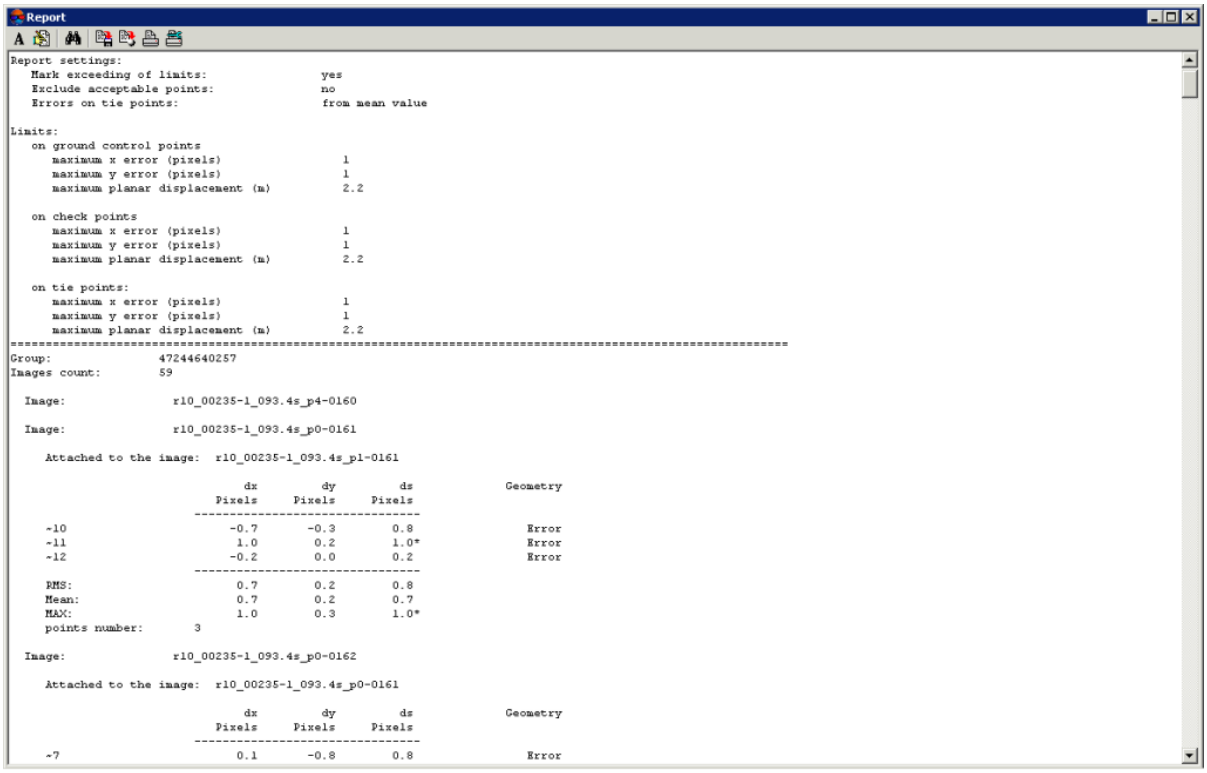
11. Click the **Report** button to view images grouping results in the **Image groups** section and analyze errors values whether they exceed the threshold specified on the **Report** tab of the **Parameters** window.

    Tie points used for creating images groups cannot be involved to block adjustment.



```
Report
Report settings:
   Mark exceeding of limits:                yes
   Exclude acceptable points:               no
   Errors on tie points:                    from mean value

Limits:
   on ground control points
      maximum x error (pixels)                1
      maximum y error (pixels)                1
      maximum planar displacement (m)         2.2

   on check points
      maximum x error (pixels)                1
      maximum y error (pixels)                1
      maximum planar displacement (m)         2.2

   on tie points:
      maximum x error (pixels)                1
      maximum y error (pixels)                1
      maximum planar displacement (m)         2.2
==================================================================================================
Group:                47244640257
Images count:         59
  Image                                 Attached to the image                RMS (pix.)     Points count            Geometry
  r10_00235-1_093.4s_p4-0160
  r10_00235-1_093.4s_p0-0161            r10_00235-1_093.4s_p1-0161                0.8              3                Error
  r10_00235-1_093.4s_p0-0162            r10_00235-1_093.4s_p0-0161                0.6              3                Error
  r10_00235-1_093.4s_p0-0163            r10_00235-1_093.4s_p0-0162                0.8              3                Error
  r10_00235-1_093.4s_p0-0164            r10_00235-1_093.4s_p0-0163                0.3              3                Error
  r10_00235-1_093.4s_p5-0161            r10_00235-1_093.4s_p5-0160                1.1*             2                Error
  r10_00235-1_093.4s_p5-0163            r10_00235-1_093.4s_p5-0164                0.5              3                Error
  r10_00235-1_093.4s_p5-0164            r10_00235-1_093.4s_p4-0164                0.1              3                Error
  r10_00235-1_093.4s_p4-0168            r10_00235-1_093.4s_p5-0168                0.1              3                Error
  r10_00235-1_093.4s_p4-0164            r10_00235-1_093.4s_p3-0164                0.1              3                Error
  r10_00235-1_093.4s_p5-0160            r10_00235-1_093.4s_p4-0160                0.3              3                Error
  r10_00235-1_093.4s_p5-0168            r10_00235-1_093.4s_p5-0167                0.2              3                Error
  r10_00235-1_093.4s_p3-0168            r10_00235-1_093.4s_p4-0168                0.0              3                Error
  r10_00235-1_093.4s_p3-0164            r10_00235-1_093.4s_p2-0164                0.0              3                Error
  r10_00235-1_093.4s_p3-0160            r10_00235-1_093.4s_p4-0160                0.2              3                Error
  r10_00235-1_093.4s_p2-0164            r10_00235-1_093.4s_p1-0164                0.1              3                Error
  r10_00235-1_093.4s_p2-0160            r10_00235-1_093.4s_p3-0160                0.2              3                Error
```

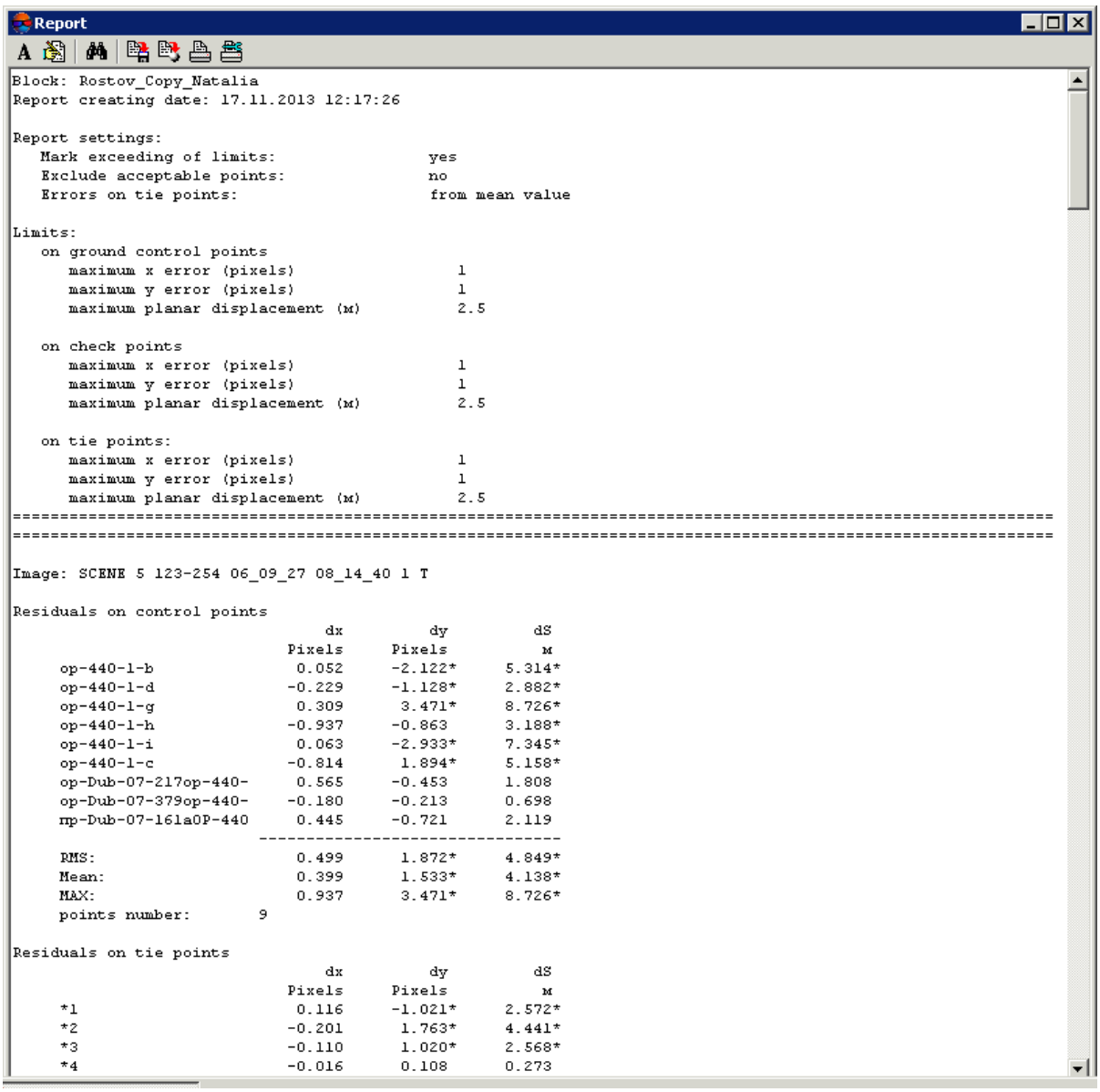
Fig. 33. Brief report on images groups



```
Report
Report settings:
   Mark exceeding of limits:                yes
   Exclude acceptable points:               no
   Errors on tie points:                    from mean value

Limits:
   on ground control points
      maximum x error (pixels)                1
      maximum y error (pixels)                1
      maximum planar displacement (m)         2.2

   on check points
      maximum x error (pixels)                1
      maximum y error (pixels)                1
      maximum planar displacement (m)         2.2

   on tie points:
      maximum x error (pixels)                1
      maximum y error (pixels)                1
      maximum planar displacement (m)         2.2
==================================================================================================
Group:                47244640257
Images count:         59

  Image:                r10_00235-1_093.4s_p4-0160

  Image:                r10_00235-1_093.4s_p0-0161

    Attached to the image:  r10_00235-1_093.4s_p1-0161

                                  dx         dy         ds            Geometry
                              Pixels     Pixels     Pixels
                          ---------------------------------
    ~10                        -0.7       -0.3        0.8               Error
    ~11                         1.0        0.2        1.0*              Error
    ~12                        -0.2        0.0        0.2               Error
                          ---------------------------------
    RMS:                        0.7        0.2        0.8
    Mean:                       0.7        0.2        0.7
    MAX:                        1.0        0.3        1.0*
    points number:        3

  Image:                r10_00235-1_093.4s_p0-0162

    Attached to the image:  r10_00235-1_093.4s_p0-0161

                                  dx         dy         ds            Geometry
                              Pixels     Pixels     Pixels
                          ---------------------------------
    ~7                          0.1       -0.8        0.8               Error
```

Fig. 34. Detailed report on images groups

When it is impossible to create images groups, RMS considerably exceeds a threshold value, and the report displays a message about error during images groups creating.



```
Report

Block: Rostov_Copy_Natalia
Report creating date: 17.11.2013 12:17:26

Report settings:
   Mark exceeding of limits:                yes
   Exclude acceptable points:               no
   Errors on tie points:                    from mean value

Limits:
   on ground control points
      maximum x error (pixels)                 1
      maximum y error (pixels)                 1
      maximum planar displacement (м)          2.5

   on check points
      maximum x error (pixels)                 1
      maximum y error (pixels)                 1
      maximum planar displacement (м)          2.5

   on tie points:
      maximum x error (pixels)                 1
      maximum y error (pixels)                 1
      maximum planar displacement (м)          2.5
=================================================================================================
=================================================================================================

Image: SCENE 5 123-254 06_09_27 08_14_40 1 T

Residuals on control points
                                  dx          dy          dS
                               Pixels      Pixels          м
     op-440-1-b                 0.052      -2.122*      5.314*
     op-440-1-d                -0.229      -1.128*      2.882*
     op-440-1-g                 0.309       3.471*      8.726*
     op-440-1-h                -0.937      -0.863       3.188*
     op-440-1-i                 0.063      -2.933*      7.345*
     op-440-1-c                -0.814       1.894*      5.158*
     op-Dub-07-217op-440-       0.565      -0.453       1.808
     op-Dub-07-379op-440-      -0.180      -0.213       0.698
     mp-Dub-07-161a0P-440       0.445      -0.721       2.119
                            ---------------------------------
     RMS:                       0.499       1.872*      4.849*
     Mean:                      0.399       1.533*      4.138*
     MAX:                       0.937       3.471*      8.726*
     points number:        9

Residuals on tie points
                                  dx          dy          dS
                               Pixels      Pixels          м
     *1                         0.116      -1.021*      2.572*
     *2                        -0.201       1.763*      4.441*
     *3                        -0.110       1.020*      2.568*
     *4                        -0.016       0.108       0.273
```

Fig. 35. Report on residuals obtained during images grouping

8.4. The “Report” tab

The **Report** tab of the **Parameters** window is used to setup display of adjustment results and their level of details in the report, as well as to define acceptable residuals during block adjustment.

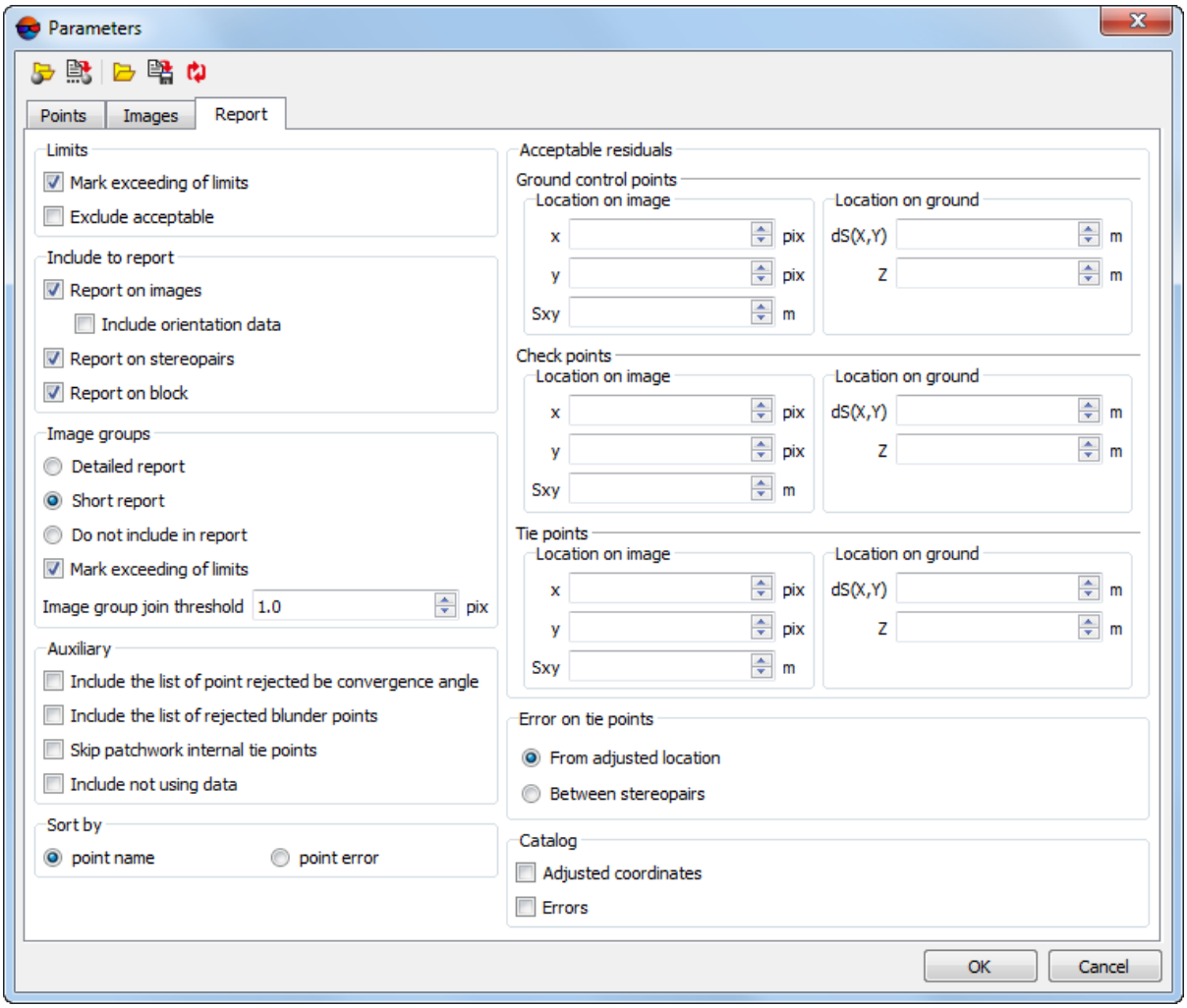


Fig. 36. Parameters on the Report tab

The **Report** tab contains the following parameters to be setup:

- the **Limits** section allows one to customize error display in the report:
  - **Mark exceeding of limits** – is used to mark residuals which exceed threshold specified in the **Acceptable residuals** section;

    Residuals which exceed threshold are marked by the $QUOTE$" * $QUOTE$" symbol.

  - **Exclude acceptable** – is used to exclude from the report an information about residuals within the threshold, specified in the **Acceptable residuals** section;
- the **Include into report** section is used to setup display adjustment results in a report:
  - **Report on images** – is used to include adjustment results by images into report;

- **Include orientation data** – is used to add to the report coefficients of transfer to image coordinates and coefficients refinements.

- **Report on stereopairs** – is used to include a list of stereopairs and values of stereoangles (convergent angles) to report;

  A list of stereopairs is displayed in report only when the adjustment is performed with stereopairs creation, i.e. The **Stereopairs** checkbox is set on the **Images** tab of the **Parameters** window.

- **Report on block** – is used to include adjustment results for the whole block to the report;

- the **Image groups** section is used to setup display image groups results in a report, which includes images acquired from the same orbit, as well as to specify image group join threshold (RMS):
  - **Detailed report** – is used to include full statistics (detailed and brief) about images groups to the report;
  - **Short report** – is used to include only brief statistics about images groups to the report;
  - **Do not include in report** – is used to exclude information about images groups from the report;
  - **Mark exceeding of limits** – is used to detect and mark image grouping errors – RMS values that exceed threshold specified in the **Image group join threshold** input field;
  - **Image group join threshold** – is used to input RMS of images group threshold value.
- the **Adjustment steps** section is used to setup a display of adjustment steps in the report:
  - **Detailed report** – is used to include to the report an information about residuals on each point of image;
  - **Short report** – is used to include to the report only general information about residuals on images;
  - **Do not include in report** – is used to exclude information about adjustment steps from the report.
- the **Auxiliary** section allows one to customize auxiliary data display in the report:

- **Include the list of points rejected by convergence angle** – the list of points rejected by convergence angle is added to the report.
- **Include the list of rejected blunder points** – a list of tie points excluded due to rough errors is added to the report;
- **Skip patchwork internal tie points** – tie points measured in one image group are not included into the report;
- **Include not using data** – all points are added into the report, none excluded.

- the **Sort by** section is used to setup display of a list of erroneous points in report:
  - **point name** – is used to display erroneous points in alphabetical order;
  - **point error** – is used to display adjustment errors in ascending order.
- the **Acceptable residuals** section is used to input residuals threshold values: **control points**, **check points** and **tie points on image** and **on ground**;

Errors in meters on scanner stereo block – is an error of intersection solution: *X*, *Y*, *Z* coordinates are calculated by stereopair after adjustment and compared with *X*, *Y*, *Z* coordinates, specified in catalogue.

Errors in pixels – is an error of resection solution: using known ground coordinates (X, Y, Z) the coordinates on image are calculated and compared with coordinates measured on image. During scanner block adjustment, in case of stereopairs absence, these errors for selected GCP or check point are shown in the **Image residuals** section on the **Information** window of the **Images** tab.

Error on image in meters – is a shift of the point on terrain, which is the distance between the point measured on the ground and the point, calculated taking into account the exterior orientation parameters.

- the **Tie points errors** section is used to choose one of the following methods of residuals calculation for tie points:
  - **From adjusted location** – is used to calculate residuals by maximal deviation from mean coordinates value, calculated for all stereopairs;
  - **Between stereopairs** – is used to calculate residuals by maximal difference between values of tie point coordinates, calculated on different stereopairs.
- the points **catalog** section allows one to customize the point catalog display:
  - **Adjusted coordinates** – is used to include to the report a list of adjusted coordinates of triangulation points (X, Y, Z);

- **Errors** – is used to add XY residuals values (Exy) and Z residuals values (Ez) to a list of adjusted coordinates.

8.5. Step-by-step adjustment

The system allows to perform step-by-step adjustment of scanner space images (for *rigorous* and *RPC* adjustment methods), divided into subblocks. Step-by-step adjustment means performing of block adjustment in several steps. At that the results of exterior orientation remain constant. Each adjustment step uses independent coordinate system, that allows to save memory.

In case of step-by-step adjustment there is a possibility of tie residuals increasing.

Step-by-step adjustment provides improving of adjustment results accuracy and is recommended in the following cases:

- block consists of images that are distinguishing by sensor type, resolution or by number of GCP with measured coordinates;
- block is formed gradually, as new data becomes available (for example, if a client provides images by lots);
- block has well-marked subblocks: for example, if there is “narrow” area with lack of images in a block; in this case it is recommended to split a block in the “narrow” area on two subblocks and to adjust them in two steps.

The system allows to split a block into subblocks manually using information about project images features shown in the **Project images** table of the **Adjustment steps** window: survey system, survey date, off-nadir angle, number of GCP and tie points.

In order to organize step-by-step adjustment procedure the **Adjustment steps** window is used.

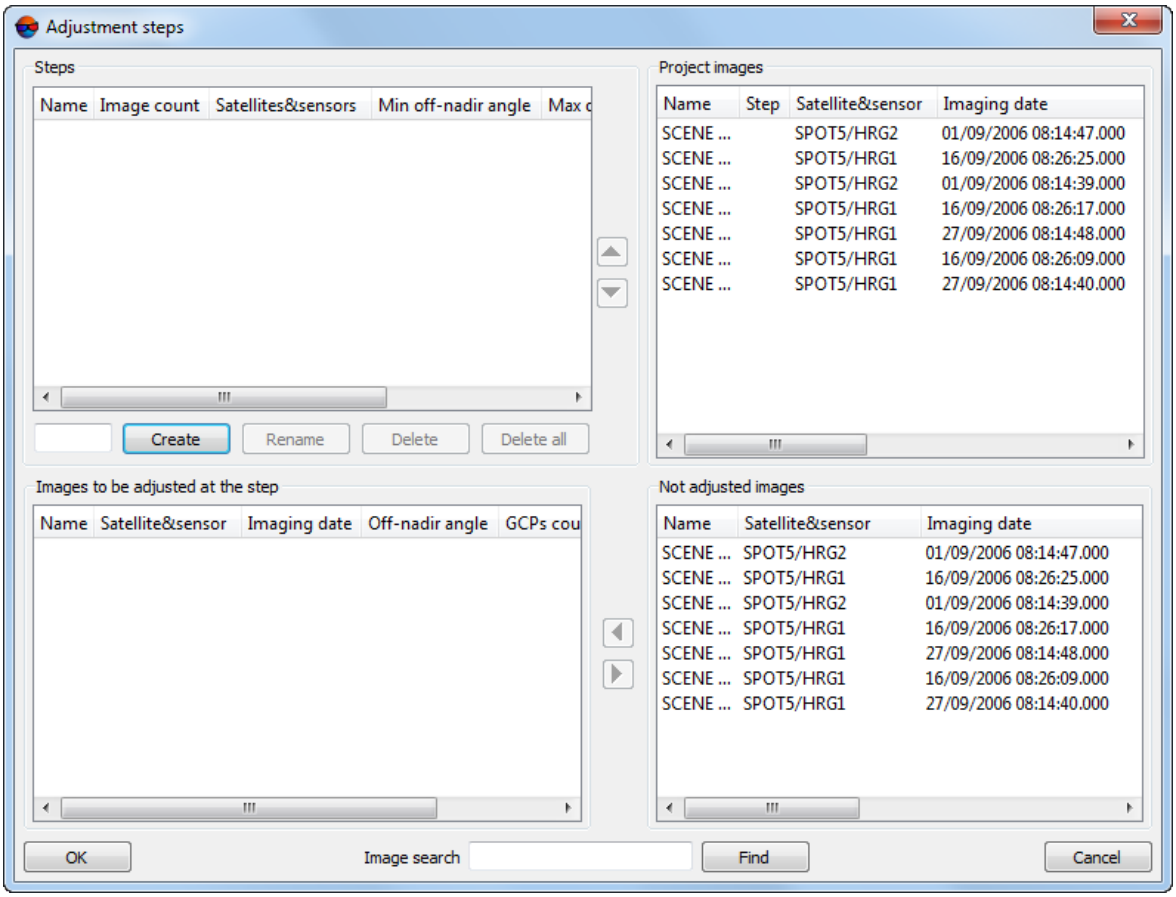


Fig. 37. The Adjustment steps window

The window includes the following tables:

- **Steps** – table of steps of subsequent subblocks adjustment, contains the following columns:
  - **Name** – user specified name of adjustment step;
  - **Images count** – number of subblock images to be adjusted on selected step;
  - **Satellite&sensor** – type of survey system which acquired images of subblock (or a list of survey systems in case of different survey systems types);
  - **Min. off-nadir angle** – minimal value of off-nadir angle among subblock images;
  - **Max. off-nadir angle** – maximal value of off-nadir angle among subblock images;
  - **GCPs count** – number of GCP, which coordinates are measured on subblock images.
- **Project images** – table of all images of a project with their parameters, contains the following columns:

- **Name** – image name;
- **Step** – step of sequential subblock adjustment;
- **Satellite&sensor** – type of survey system (satellite and sensor);
- **Imaging date** – date and time of survey;
- **Off-nadir angle** – off-nadir angle (in degrees);
- **GCPs count** – number of GCP with measured coordinates;
- **TPs count** – number of tie points with measured coordinates;
- **Strip** – a name of the image strip.

- **Not adjusted images** – table of images, that are not collected to subblocks to perform step-by-step adjustment, contains the following columns:
  - **Name** – shows image name;
  - **Satellite&sensor** – type of survey system (satellite and sensor);
  - **Imaging date** – date and time of survey;
  - **Off-nadir angle** – off-nadir angle (in degrees);
  - **GCPs count** – number of GCP with measured coordinates;
  - **TPs count** – number of tie points with measured coordinates;
  - **Strip** – a name of the image strip.
- **Images to be adjusted at the step** – table of subblock images that are used for adjustment step, selected in the **Steps** table.

To perform step-by-step adjustment of scanner space images perform the following actions:

1. Click the **Options** button. The **Parameters** window opens.
2. On the **Images** tab in the **Adjustment steps** section set the **Use adjustment steps** checkbox.
3. Click the **Steps...** button. The **Adjustment steps** window opens.

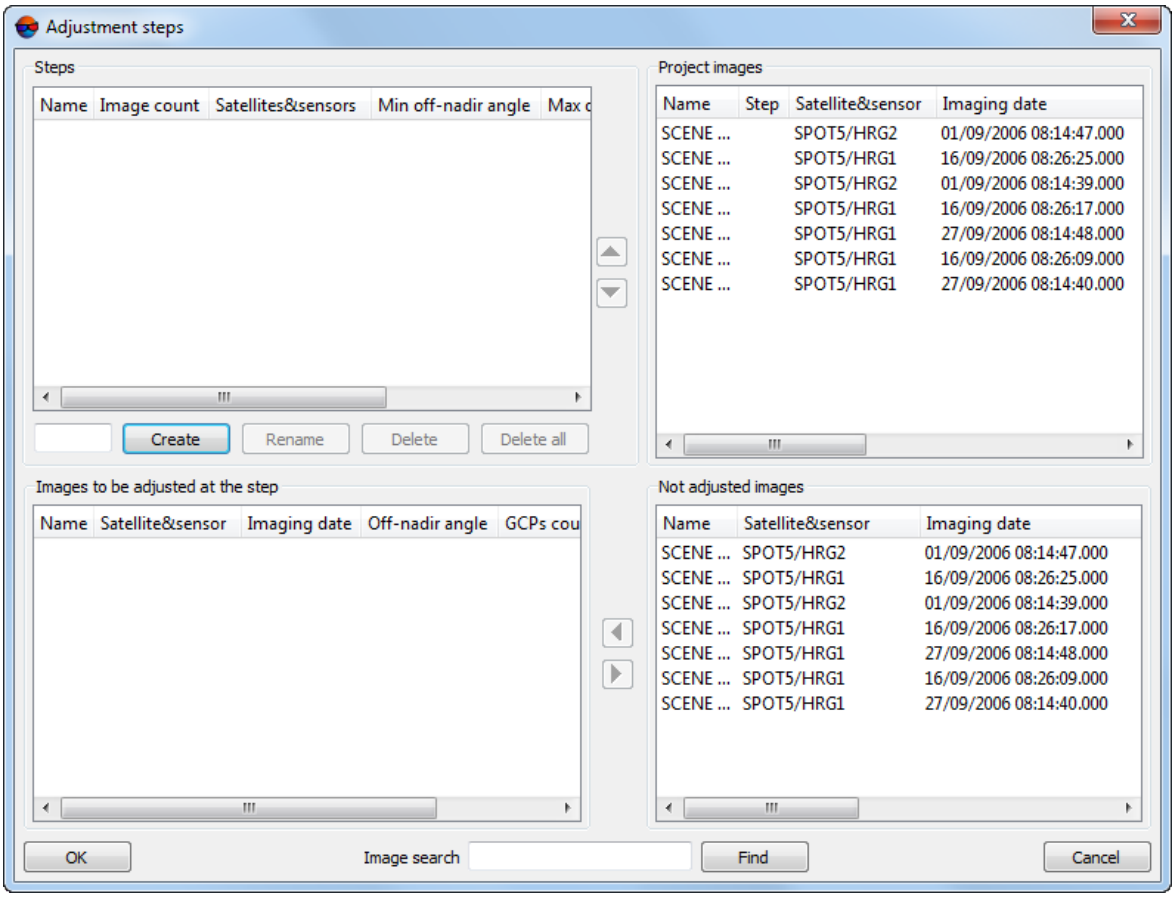


Fig. 38. The Adjustment steps window

4. Specify step's name in the input field, located in the lower part of the **Steps** table and click the **Create** button.

5. In the **Not adjusted images** table select multiple images of subblock, which should be adjusted on the created step. Use the **Ctrl+Shift** shortcut and click the ◀ button. As a result in the **Images to be adjusted at the step** table will show subblock images selected for adjustment step.

6. To create further steps of adjustment, repeat steps 3, 4, 5 as many times as necessary.

   In order to edit entries in the **Steps** table use the **Rename**, **Delete**, **Delete all** buttons. The ▲ and ▼ buttons are used to change order of steps during adjustment.

   To perform the **image search** in **Project images** and **Not adjusted images** tables, input the search query in appropriate field and click the **Find** button.

7. Click OK to complete setup of adjustment steps forming.

8. In the **Parameters** window click the **Apply to all** button.

9. Setup the rest of the adjustment parameters and click OK.

10. Click the button in the **Block adjustment** toolbar to launch step-by-step adjustment.

8.6. Recommendations on monoblock adjustment

Monoblock – is a set of overlapped images, which usually have small overlap area. Most often a monoblock consists of images acquired from different sensors and with significant time interval between surveys.

When processing blocks containing images with significant survey time interval, work of correlator during automatic measurement of tie points is hampered. It takes place due to following reasons:

- different luminosity parameters;
- survey in different seasons;
- different images resolution;
- change of situation on terrain (for example, construction of new objects, forest cutting);
- appearance of oblique images since off-nadir angle differs greatly for different block images;
- data relative accuracy depends on absolute accuracy of satellite position on the orbit.

There are the following recommendations for monoblocks processing on different steps of adjustment:

1. On block forming step images are distributed to strips depending on a set of initial data.

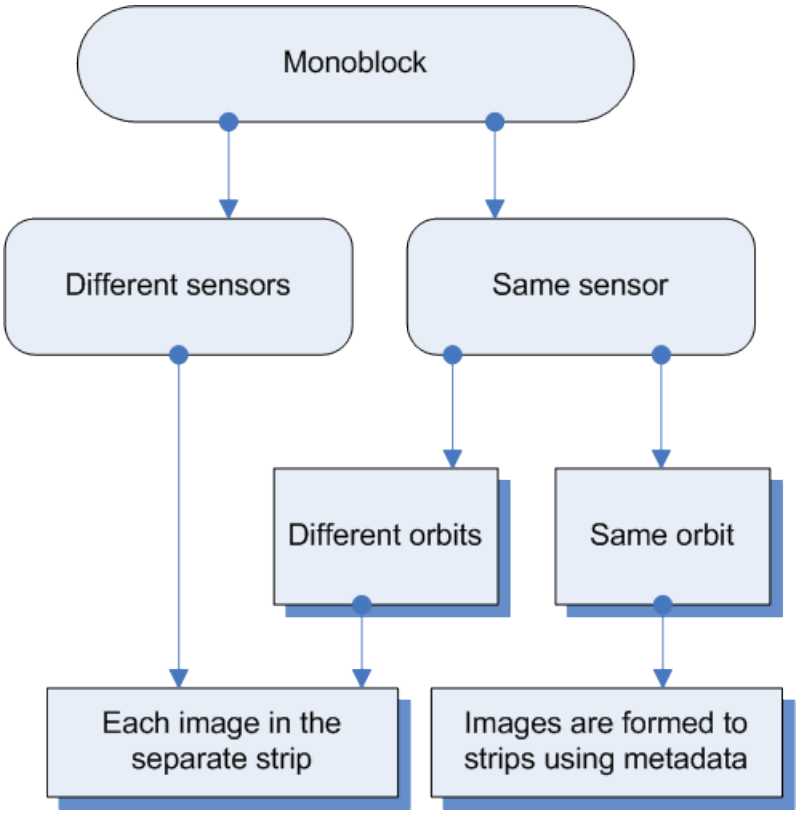


Fig. 39. Scheme of monoblock forming in the system

2. On step of triangulation points measurement there are the following recommendations concerning setup of parameters of automatic tie points measurements:

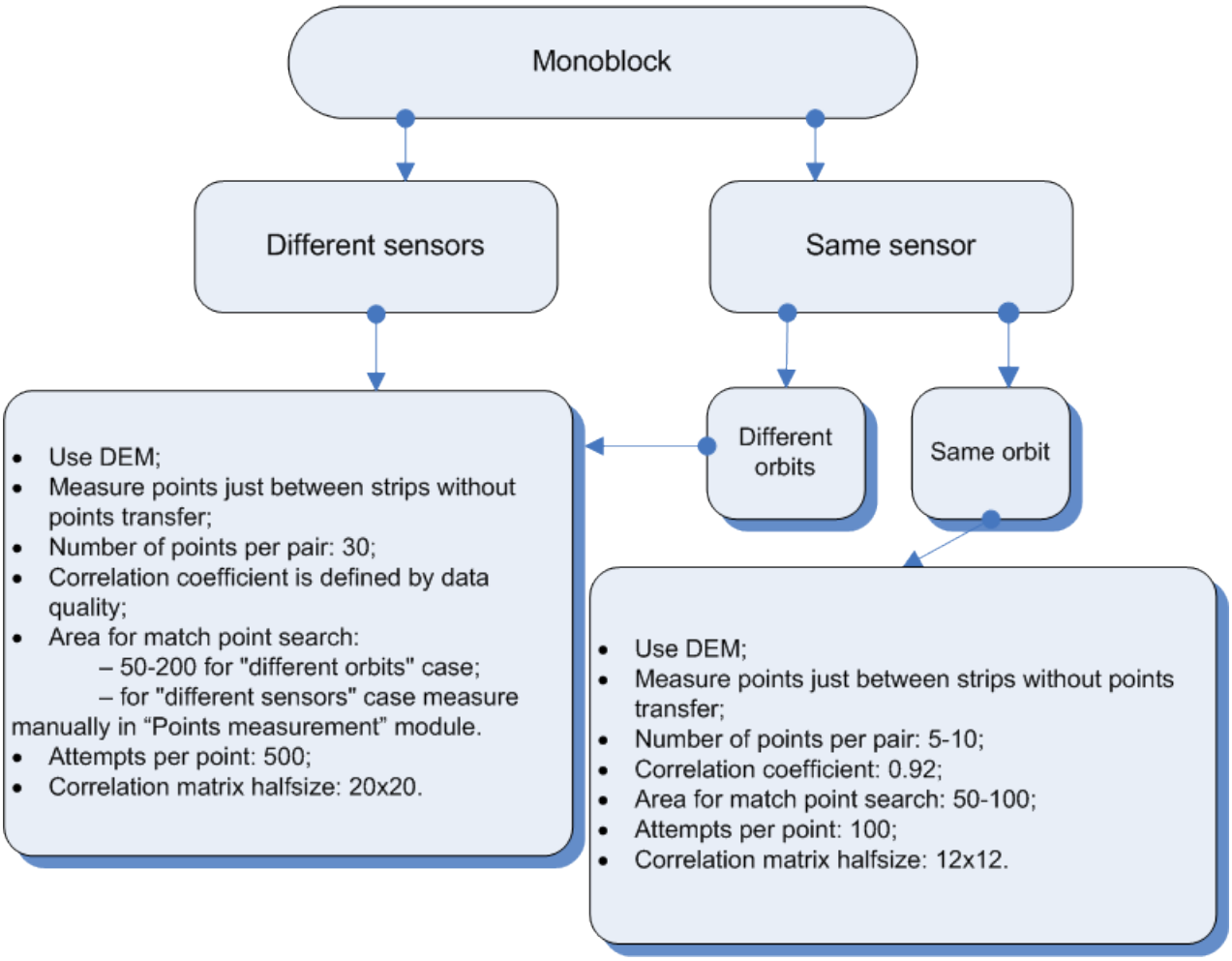


Fig. 40. Parameters of automatic correlation for monoblock

3. On the step of mono block adjustment perform the following actions:

☞ It is recommended to perform the mono block adjustment using the method of successive approximations with filtering.

1. Click the button of the **Block adjustment** toolbar. The **Parameters** window opens.

2. On the **Points** tab input the following parameters:

   - in the **Points coordinates accuracy** section input 0.5 pix to the **Image measurements RMS** input field;

   - in the **Unity-weighted geodetic coordinates accuracy** section input 1 m to the **plane** and **height** input fields;

- in the **Points usage** section input 0.01 to the **Coordinates delta threshold (pix)** input field;
- in the **DTM for adjustment** section set the **Use DEM** option and load the DEM from file.

During mono block adjustment it is highly recommended to use DEM due to insufficient images overlap area. Otherwise, there are errors in the correlator work, as well as errors in calculating Z coordinates of tie points measurements.

3. Click OK.
4. Click the button of the **Block adjustment** toolbar.
5. Tie points with tie residual that exceeds 10-20 pixels transfer into **Excluded** status in the **By ties** section of the **Information** window (see Section 5.5).
6. Set the **Use ties in block adjustment** checkbox in the **Points usage** section on the **Points** tab of the **Parameters** window.

For images with 'low-quality' exterior orientation parameters it is recommended to set the **Affine** option in the **Parameters** window on the **Images** tab in the **Refinement** section.

For images with precise exterior orientation parameters it is recommended to set the **None** in the **Parameters** on the **Images** tab in the **Refinement** section. In this case the refinement will be not calculated.

7. Click the button of the **Block adjustment** toolbar to adjust the block once more.
8. Tie points with tie residual that exceeds 2-5 pixels transfer into **Excluded** status in the **By ties** section of the **Information** window (see Section 5.5).
9. Perform adjustment accuracy control (see Section 11).

All steps of adjustment procedure require evaluation of adjustment results accuracy. Here the tie points measurements and exterior orientation parameters consistency could be evaluated. During monoblock adjustment, the adjusted estimate of the accuracy of tie points coordinates in meters is displayed as 0. This is due to the fact that DEM serves as a reference data for the tie points. Therefore, quality control of monoblock processing reduces to estimating errors on tie points.

8.7. Number of points recommended for adjustment of scanner block

There are some recommendations about number of GCP and check points used for different methods adjustment of images included to scanner mono/stereo blocks.

For satellite scanner images it is possible to use only XYZ GCP (with X, Y, Z coordinates).

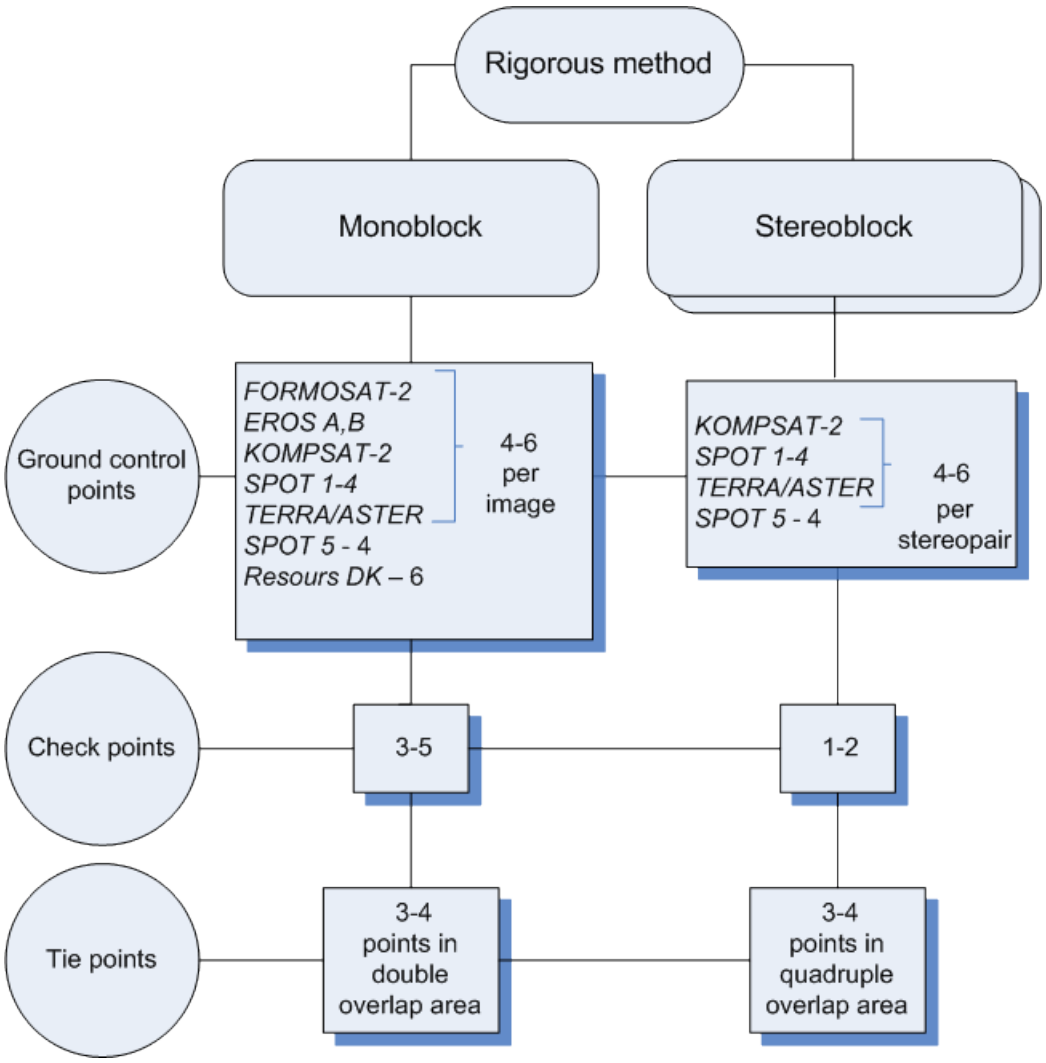


Fig. 41. Number of points recommended for adjustment of scanner block by rigorous method

If a monoblock contains images with triple or quadruple overlap area, it is recommended to measure several points in this area.

Number of GCP could be decreased due to tie points measured in triple or quadruple overlap.

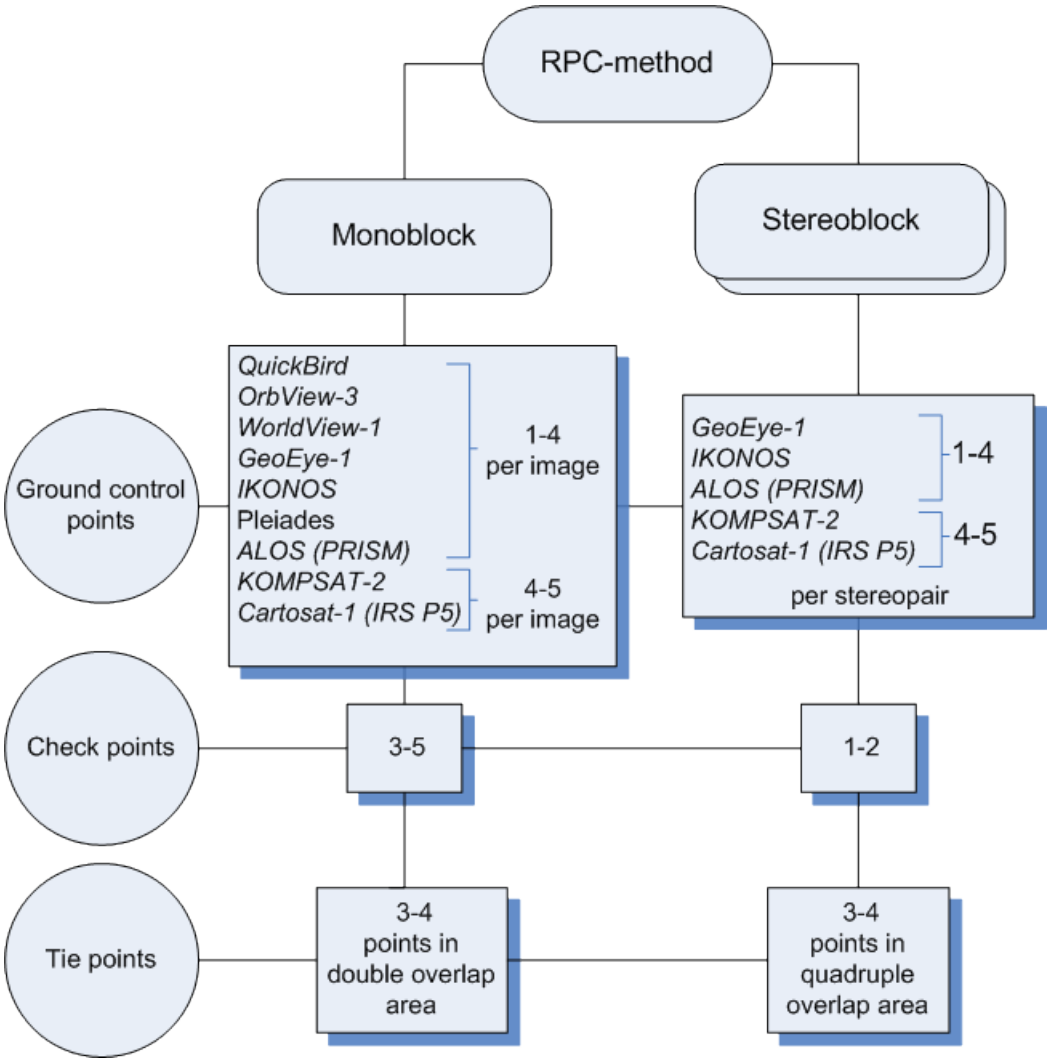


Fig. 42. Number of points recommended for adjustment of scanner block by RPC method

Number of GCP could be decreased due to tie points measured in quadruple overlap.

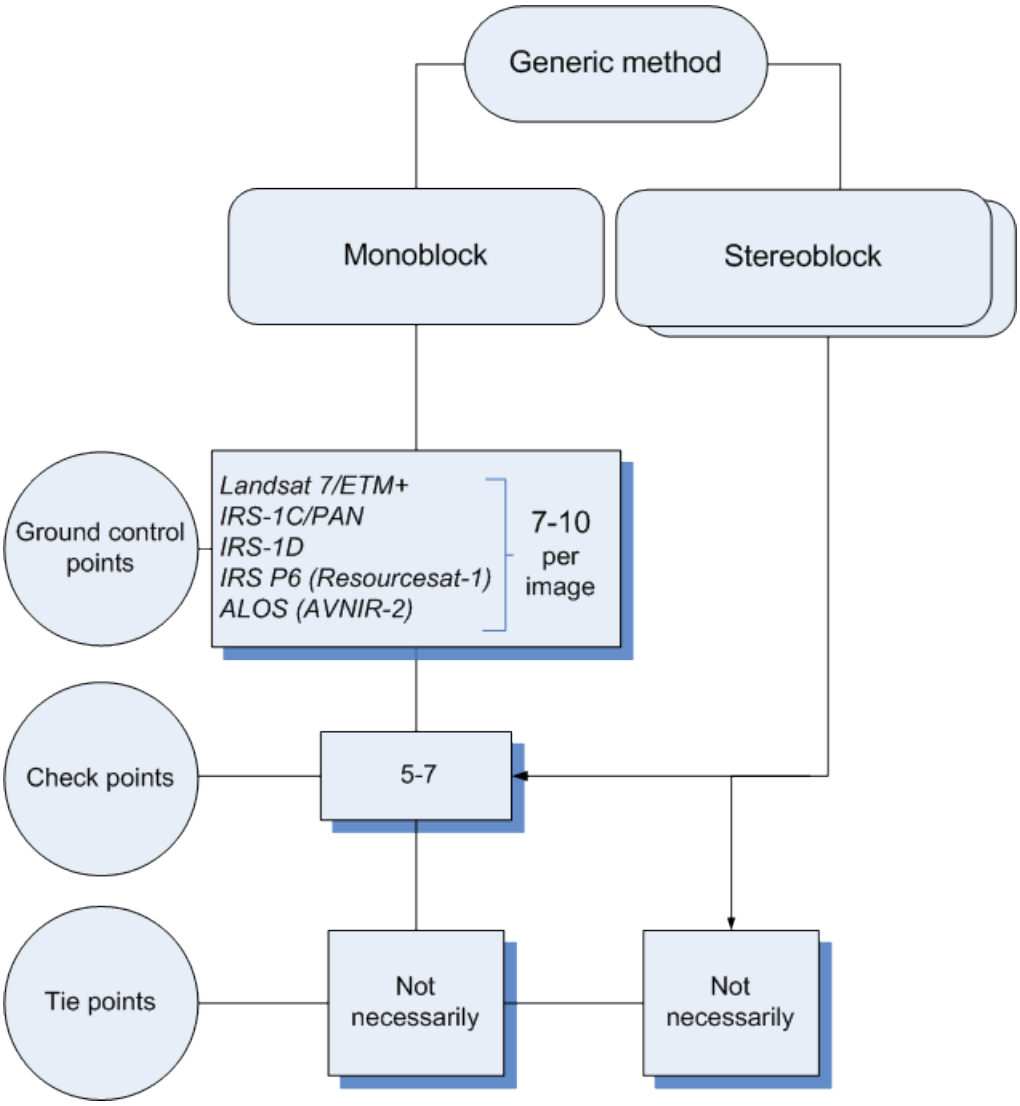


Fig. 43. Number of points recommended for adjustment of scanner block by generic method

Recommended number of check points on images is not absolute and in many cases is determined by the customer requirements to specific project. Nevertheless, it is necessary to have check points available for objective estimation of adjustment accuracy.

9. Adjustment procedure

In order to perform adjustment, it is necessary to setup parameters of project adjustment and click the **Compute** button. The calculation procedure is started and the window opens where the adjustment operation status is displayed.

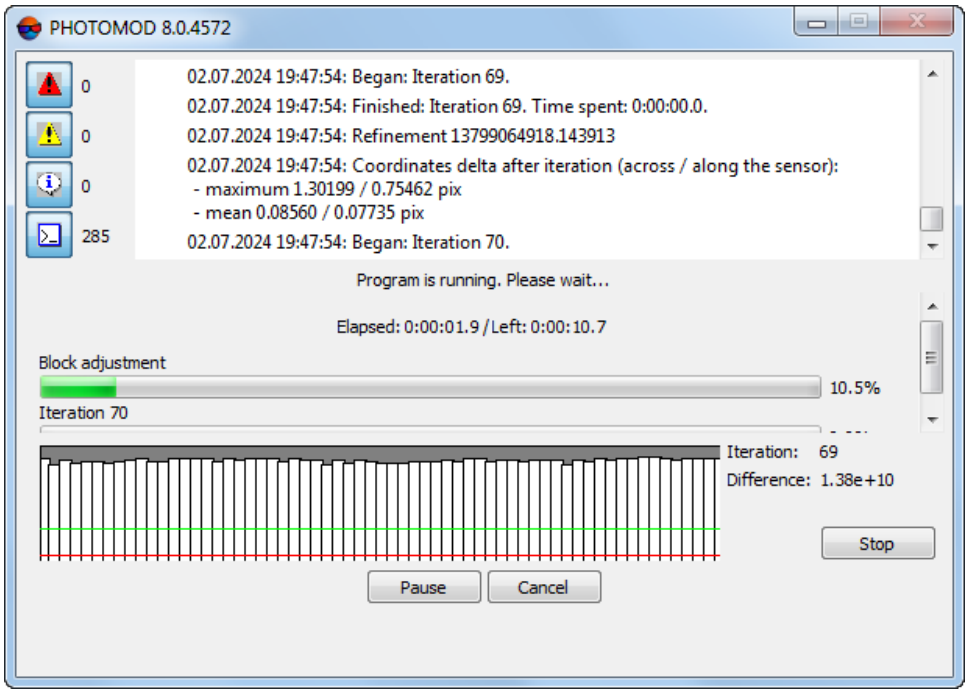


Fig. 44. Window of adjustment procedure status

Adjustment operation convergence is represented by the diagram. The window also shows iteration number, adjustment method, and a value of refinement.

If the iterative process does not converge, interrupt the adjustment operation using the **Stop** button to display a result obtained on current iteration. In order to delete all the adjustment results click the **Cancel** button.

Non-convergent adjustment may be caused by relative orientation errors, errors in GCP coordinates or by incorrect adjustment parameters (see Section 12), or due to wrongly defined coordinate system (right-left).

Adjustment procedure interrupts only between iterations, at that the adjustment results are saved.

In order to save satisfactory adjustment results click the button of the **Block adjustment** toolbar. Pass to further project processing (see the "Project creation" User Manual).

The button on the **Adjustment** toolbar is used to restore current block status. Also it allows to load adjustment results after project loading.

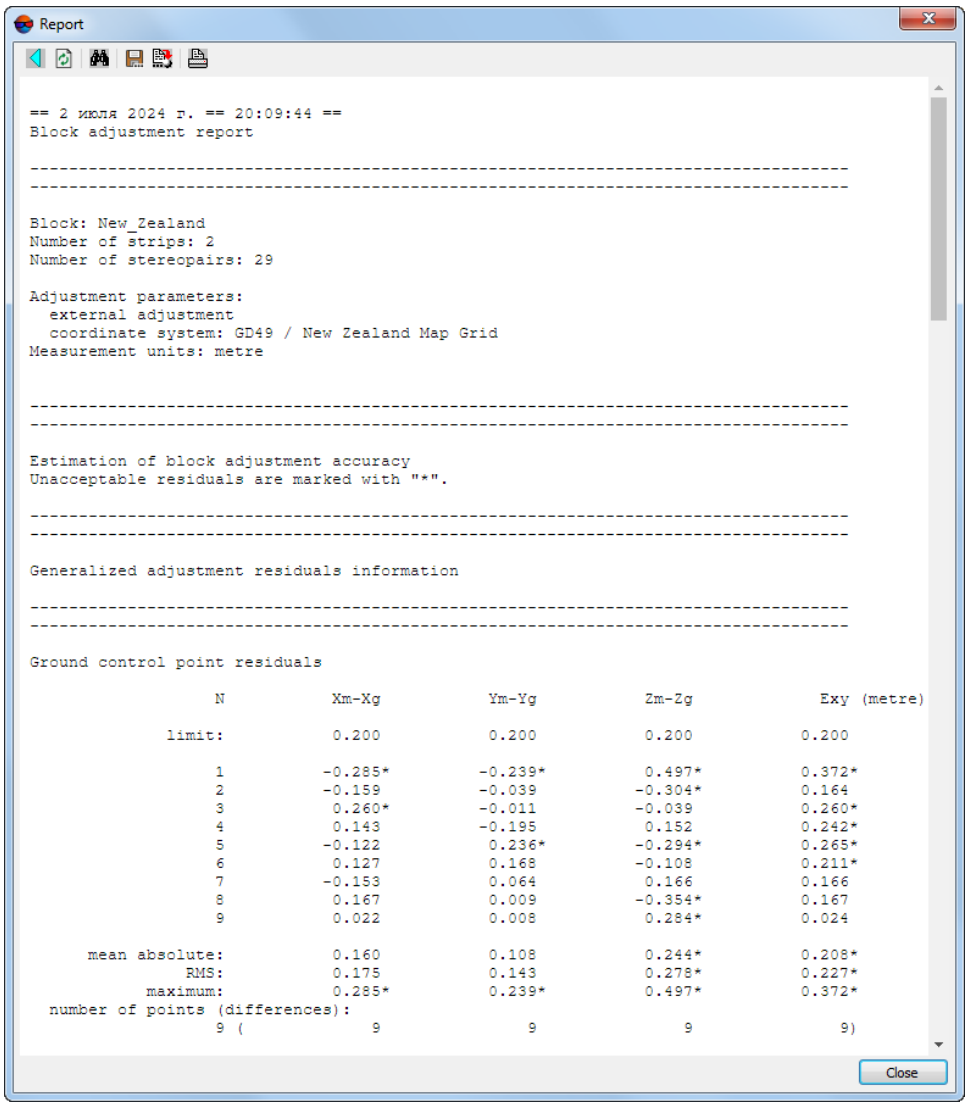
When adjustment brings unsatisfactory results and it is necessary to bring the block back to its initial status (as it was prior to adjustment launch), click the button on the **Adjustment** toolbar.

10. Creating adjustment report

The system provides possibility to view full statistics of adjustment, summary information about adjustment residuals and control data.

To do this perform the following:

1. Click the button on the **Block adjustment** toolbar;
2. Set the needed **Parameters** in appropriate window, for the current project type: central projection (see Section 7.4) or scanner block (see Section 8.4);
3. Click OK. The **Report** window opens:



```
== 2 июля 2024 г. == 20:09:44 ==
Block adjustment report

--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

Block: New_Zealand
Number of strips: 2
Number of stereopairs: 29

Adjustment parameters:
  external adjustment
  coordinate system: GD49 / New Zealand Map Grid
Measurement units: metre


--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

Estimation of block adjustment accuracy
Unacceptable residuals are marked with "*".

--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

Generalized adjustment residuals information

--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

Ground control point residuals

                   N          Xm-Xg          Ym-Yg          Zm-Zg            Exy (metre)

              limit:          0.200          0.200          0.200           0.200

                   1         -0.285*        -0.239*         0.497*          0.372*
                   2         -0.159         -0.039         -0.304*          0.164
                   3          0.260*        -0.011         -0.039          0.260*
                   4          0.143         -0.195          0.152          0.242*
                   5         -0.122          0.236*        -0.294*          0.265*
                   6          0.127          0.168         -0.108          0.211*
                   7         -0.153          0.064          0.166          0.166
                   8          0.167          0.009         -0.354*          0.167
                   9          0.022          0.008          0.284*          0.024

      mean absolute:          0.160          0.108          0.244*          0.208*
                RMS:          0.175          0.143          0.278*          0.227*
            maximum:          0.285*         0.239*         0.497*          0.372*
  number of points (differences):
                   9 (             9              9              9               9)
```

Fig. 45. The window of adjustment report (central projection)

The toolbar of the **Report** window contains the following buttons:

- – allows to return to previous view of the report;
- – allows to refresh the report;
- – allows to start search in report's text (**Ctrl+F**);
- – allows to save a report into text file;

The report also saves in the *\backup* project folder automatically with the adjustment results (only for central projection images).

- – allows to save a report into system resources;
- – allows to print a report.

The adjustment report displays the following values:

- residual values calculated on GCP, check, tie points, and projection centers for the whole block and for each point;
- catalogue of points coordinates;
- images exterior orientation parameters;
- GPS corrections;
- corrections for exterior orientation parameters.

Report content is setup on the **Report** tab of the **Parameters** window (see Section 8.4 and Section 7.4).

Residuals and errors are displayed in the report as follows:

- *X, Y, Z* – coordinates values taken from model (from strip when using *independent strips method*, from stereopair when using *independent stereopairs method*);
- *X1, X2, Y1, Y2, Z1, Z2* – values of points coordinates on two different models;
- *Xcp, Ycp, Zcp* – values of points coordinates, averaged over all models;
- *Xg, Yg, Zg* – geodetic value of points coordinates, specified by the user for GCP and check points;
- *Exy, Ez* – average residuals of points XY and Z coordinates;
- *dX, dY, dZ, dS* – discrepancies on GCP;
- *dX, dY, dZ, dXY* – GPS corrections on projection centers.

11. Correcting errors in the positions of triangulation points

Block adjustment accuracy control includes checking the magnitude of errors in determining XY- and Z-coordinates of triangulation points. For ground control and tie points, XY- and Z-coordinate errors are displayed visually as various error vectors, and the numerical values of the errors are displayed in the adjustment report. Block adjustment accuracy control includes checking the magnitude of errors in determining XY- and Z-coordinates of triangulation points.

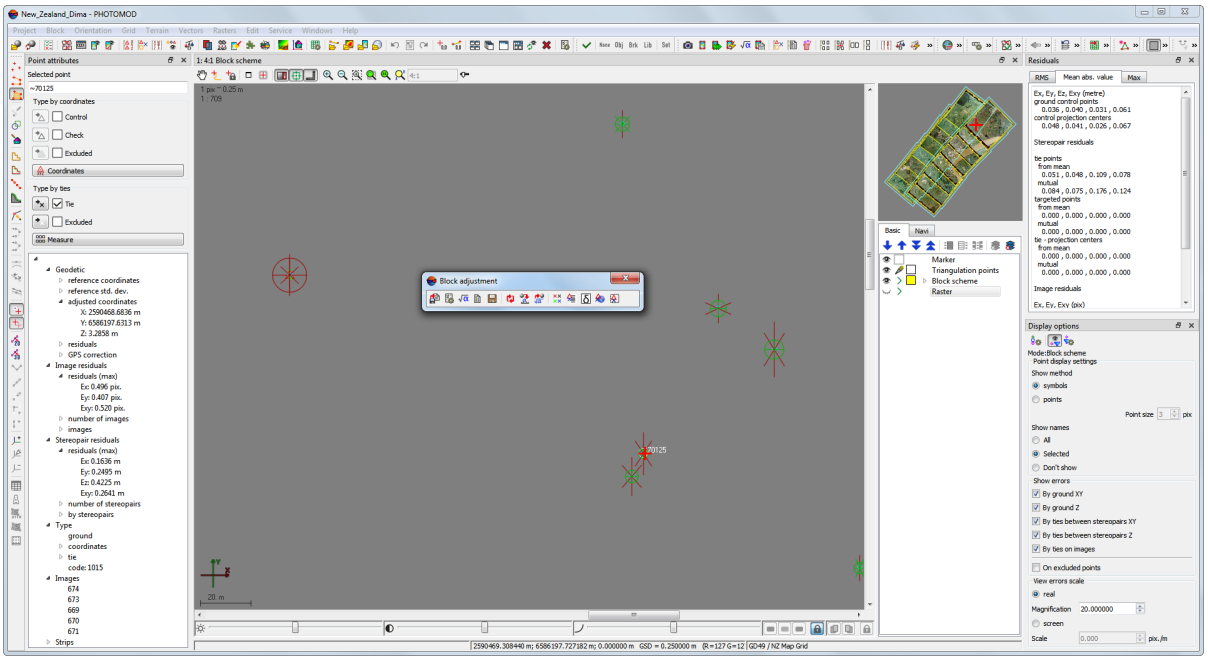


Fig. 46. The triangulation points and residuals vectors

The triangulation points and residuals vectors displaying parameters are described above (see Section 5.1 and Section 5.2).

The causes of rough errors, as a rule, can be incorrectly specified (or, in rare cases, initially incorrect) coordinates of ground control points, as well as errors in the positioning of tie and GC points in the images. It is possible to improve unsatisfactory adjustment results, which can be partly caused by the errors described above, by editing the triangulation points and readjusting the project:

- For tie points:
  - Deleting a tie point from the project;
  - Assigning the tie point the **Excluded** type – to exclude a point from the adjustment process without deleting it from the project;
  - Correcting the point's position in images (see below).

- For GCPs:
  - Deleting a GCP from the project;
  - Assigning the GCP the **Excluded** or **Check** point type.

    The **Check** points is not involved into block adjustment (as a GC point), but is used as a tie point. It is also can be used for the further accuracy control. The **Excluded** points type is used for temporal point exclusion from GC points list, for example, to exclude unmeasured GC points prior to block adjustment.

  - Correcting the position of the GCP in the images (for example, the GCP was incorrectly measured in the images due to an insufficiently detailed outline);
  - Correcting entered geodetic coordinates of the GCP (for example, the operator made an error when entering the coordinates of the point).

In order to change point's type or position perform the actions described above (see Section 5.5).

Click the button on the **Block adjustment** toolbar to complete changing point's position on image.

In order to change triangulation points position on images perform the following actions:

1. On a block scheme or in a list of points select a point (or several points), which residual exceeds specified threshold value (the residuals vectors are shown by red color).

   Acceptable residuals are set in the appropriate section of the **Report** tab of the adjustment **parameters** window (see Section 7.4).

2. In the **Points attributes** window click the **Measure** button. The **Points measurement** window opens (with images on which the selected points are located).

   For details see the "The "Points measurement" module" chapter in the "Aerial triangulation" User Manual.

   The list with in only selected points is displayed in the **Triangulation points** window. Only these are also displayed on images.

   Tie and ground control points are distributed into the corresponding tabs of the **Triangulation points** window (,).

   By default the filter is applied on both **Triangulation points** window tabs (display points selected on the adjustment stage). The following buttons on a toolbar of the **Triangulation points** window (in Tie points tab) allows to change the filter for points list, that are displayed in the table and on images:

- – all points;
- – points on open images;
- – common points on open images.

3. [optional] In order to display GCP residuals vectors ( ) and/or tie residuals vectors ( ) click the appropriate buttons in leftward toolbar of the **Points measurement** window;

4. Move a point manually or using correlator (see description of correlator work in the "Aerial triangulation" User Manual). Each image window in the module contains the following buttons of upper toolbox used to work with image:

   - – allows to move or add selected tie or GC point to marker's position;
   - – allows to move a point along tie residual vector;
   - – allows to move a point along GCP residual vector;
   - – allows to remove measurement results for point selected on image;

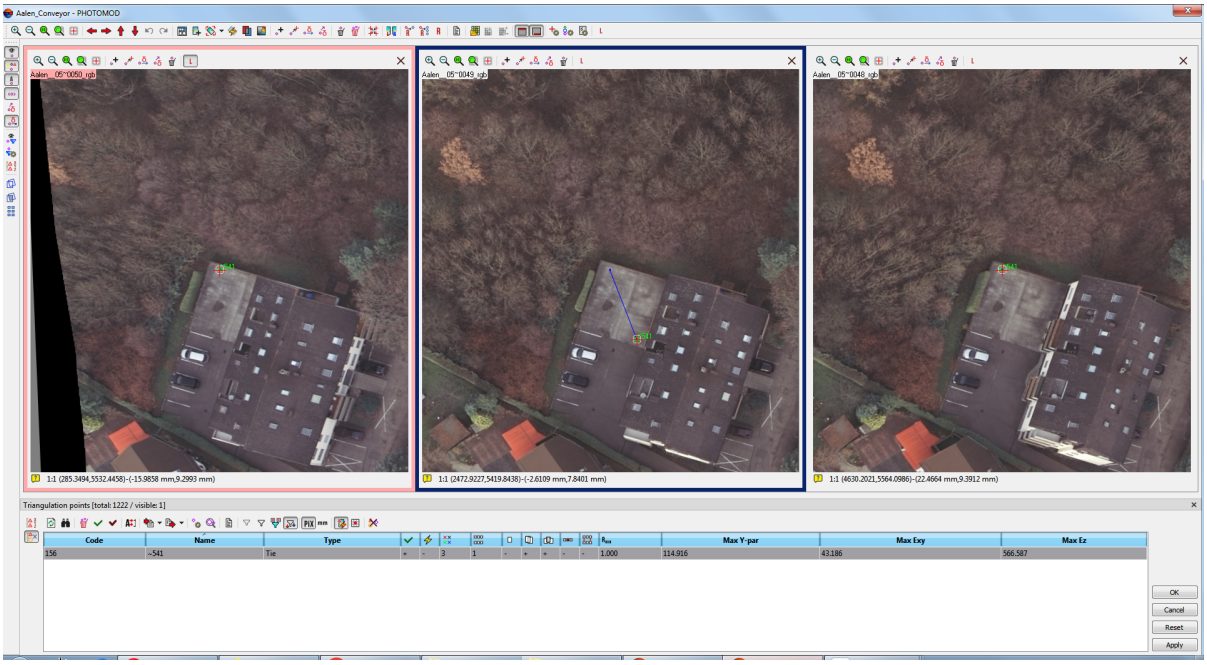


Fig. 47. Editing tie point location. Tie residuals vector (on the central image) is colored blue

5. Click OK to exit the **Points measurement** module.

6. Click the button on the **Block adjustment** toolbar to complete changing point's position on image.

In order to use interstrip points and points non-transferred in some strip in the adjustment by *independent strips method* or *independent stereopairs method*, it is necessary to measure coordinates of the points on adjacent images inside the strip during aerial triangulation or in the **Points measurement** window (see the "Aerial triangulation" User Manual).

In order to change geodetic coordinates of points on image perform the following actions:

1. On a block scheme or in a list of points select a GC point;

2. In the **Points attributes** window click the **Coordinates** button.The **Triangulation points** window opens (on **GCP list** tab). In this window the information about selected GCP is displayed.

   Double-click of points string allows to open the **Points Measurement** window and change point's position (see above).

3. Select the GC point in **Triangulation points** window table by **left mouse button** click. Click the button in **Triangulation points** toolbar. The window **Point properties** opens:

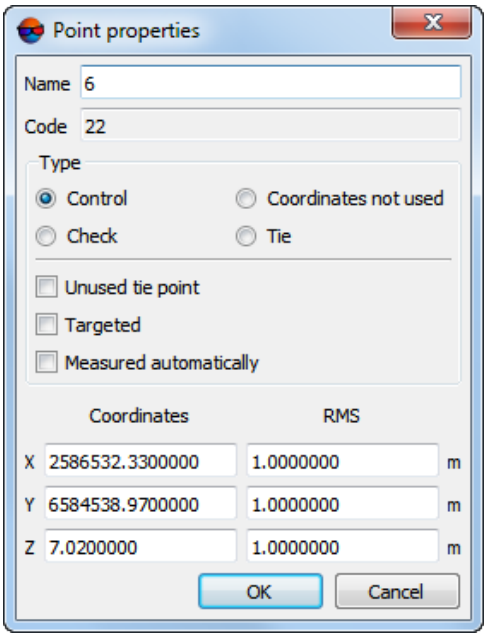


Fig. 48. Point properties

For GC points the geodetic **Coordinates** and **RMS** of point are displayed. Specify the needed parameters and click OK to close the window.

12. Stages of accuracy control

12.1. Adjustment control in free model

12.1.1. Splitting on subblocks

Splitting on subblocks is a necessary condition for adjustment control operation in free model in the following cases:

- if the block contains many blunders, it is easy to detect them by splitting on sub-blocks in such a way that each sub-block would contain not more than one blunder;
- if a processed block has a length more than 20 bases, time for sub-block adjustment is less than time for adjustment of the whole block.

12.1.2. Blunders control in camera focal length

In order to detect blunders in camera focal length value, it is recommended to input a survey basis approximately. If a basis value was input correctly, the **Scale** section on the **Report** tab of the **Parameters** window displays correct value of survey scale after adjustment. If the difference between calculated height values of triangulation points and projection centers differs significantly from real ones at that, than more likely focal length was input incorrectly.

During adjustment in *free model* values of calculated Z-coordinates of projection centers are close to 0.

During adjustment in *free model* values of calculated Z-coordinates of triangulation points are negative and close to survey altitude by absolute value.

During adjustment in *free model* small errors in value of camera focal length cannot be detected. In this case it is recommended to perform adjustment using GCP.

12.1.3. Blunders control in strips tying

In order to detect blunders in interstrip tie measurements it is recommended to adjust sub-blocks using *independent strips method* in *free model*.

In case of long strips (20 bases) the errors might exceed calculated ones in 10 20 times.

It is recommended to split on parts strips with length more than 10 20 bases.

In order to detect errors within a threshold, it is necessary to specify a survey basis with accuracy of 30-50%. Operation of checking correctness of specified basis is performed after adjustment in the **Parameters** window on the **Report** tab in the **Scale** section by calculated value of survey scale.

In order to obtain correct error values (in meters), it is necessary to specify a survey basis (with accuracy of 30-50%). Correctness of specified basis checks after adjustment in the **Parameters** window on the **Report** tab in the **Scale** section by calculated value of survey scale.

For blocks with strips of moderate length (up to 15 images), it is recommended to adjust the whole block using *independent strips method* in *free model*.

12.1.4. Intermediate control of tie measurements blunders

After control of adjustment that was performed by *independent strips method* in free model, it is recommended to execute control tie points measurement blunders using adjustment by *independent stereopairs method*. The errors that are not exceeding 2 4 thresholds are acceptable.

12.1.5. Blunders detection on interstrip not-transferred points

In order to detect blunders in interstrip points, non-transferred in images overlap on one of the strips, it is recommended to perform block adjustment using *independent stereopairs method* in *free model* (prior to bundle adjustment).

"Not-transferred" point – points which coordinates are measured only on a single image in one strip (it is not measured in overlap of adjacent images in a strip).

If point's coordinates are measured in adjacent images overlap area, it is necessary to check tie points distribution in triplets corresponding to this point. If the ties are located in some small area of overlap, it is recommended to measure additional tie points on the whole overlap area.

12.1.6. Control of errors of tie points measurements

In order to detect blunders in interstrip and inside strip tie points measurements, it is recommended to perform block adjustment in free model using *independent stereopairs method*, then adjustment the block by *bundle adjustment method*. It is recommended to alternate two ways of adjustment until obtaining error values, that not exceed 75% of tie errors threshold before executing adjustment with GCP, since using GCP data leads to increasing of error values.

The first adjustment should be performed by *independent stereopairs method*, as it is more stable. Then it is possible to alternate *independent stereopairs* with *bundle* adjustment.

To obtain correct error values of interstrip and inside strip tie points measurements that within threshold, it is recommended to set survey basis approximately with 10–20% of accuracy.

12.1.7. Control of errors of automatic tie points measurements

During automatic tie points measurement it is possible to face a situation when obviously erroneous points are corrected, and maximal (out of tolerance) adjustment error exists on points measured correctly. One of the reasons may be incorrect work of automatic tie points measurement algorithm (due to complex terrain, wrong algorithm settings).

In order to detect errors of automatic tie points measurement it is recommended to check regularity of points' distribution and errors absence on closest stereopairs and triplets.

It is also recommended to perform control of each point, starting from points with maximal error. Perform the following actions to do this:

1. Check point location (measurement) in stereomode:
   - point should not be placed in trees shadow;
   - correctness of point position in Z-axis.
2. Check point recognition correctness:
   1. Measure one more point near point under test (on a distance not exceeding of about 1/10 of stereopair overlap area).
   2. After adjustment check error value on both points:
      - if the errors on both points are of the same value (direction and size), then the point is recognized correctly;
      - if error on the tested point is within tolerance threshold, and error on a new point has maximal value, it is necessary to perform control of points regular distribution;
      - if the errors on both points have a value close to accuracy limit, it is recommended to complete point's validation.
3. Check a few closest tie interstrip points (all of them or minimum 3 ones regularly distributed in each stereopair overlap where the point exists, and some more points in a distance of 1 3 stereopairs).
4. Check errors on new tie points:
   - measure one tie point in those triplets where the tested point is located;
   - check errors on new tie points after adjustment operation. The error will appear on really erroneous points.

If it is impossible to identify erroneous points after all the procedures, it is necessary to check other possible sources of errors:

- interior orientation errors;
- deformations of some particular image of the block;
- incorrect choice of objects for points' measurements (see Section 13.7).

To obtain tie points errors that are within a tolerance threshold, it is recommended to delete points with maximal error in adjacent stereopairs and to re-measure points in this area manually.

12.2. Adjustment control with geodetic reference

12.2.1. Control of coordinate system correctness

If the adjustment of georeferenced block fails, it is necessary to check coordinate system selection.

In order to detect coordinate system selection, perform the following actions:

1. Check if it is correct selection of left-handed or right-handed coordinate system:
   - adjust block in the Cartesian *right*-handed coordinate system;
   - adjust block in the Cartesian *left-handed* coordinate system;
   - compare the adjustment results and check for residuals.
2. Selecting of the coordinate reference system type window opens. Check correctness of a type of used coordinate system by comparing coordinates of 3 GCP, that are clearly not lie along a straight line, with their location on block scheme before adjustment.
3. Make sure that there are no input mistakes in coordinates – presence of typos in coordinates (extra digits, missed digits, incorrect zone number).

12.2.2. Control of adjustment performed using projection centers coordinates

In order to define errors of adjustment with specified projection centers coordinates, perform the following actions:

1. Select GCP with a blunder on a block scheme.

2. In the **Point attributes** window click the button, to change selected GCP into check point.

3. Click the button on the **Block adjustment** toolbar to perform a block adjustment.

4. Check for the presence of the random component of the error.

If there is a big *constant* Z-error in a block after adjustment, it is recommended to check camera focal length and coordinate system selection.

If there is a big *systematic* Z-error in a block after adjustment, Z-error vectors in a block center are directed to opposite side in relation to vectors located on the edges of a block. In this case it is recommended to check coordinate system selection (to consider the curvature of the Earth) and check interior orientation (to consider distortion).

12.2.3. Control of adjustment performed without projection centers

If there is big enough amount of GCP (approximately 10 and more) on a block, it is recommended to set small weight of equation on GCP (0.01–0.1) and adjust the block without projection centers.

If there is a big *systematic* Z-error in a block after adjustment, Z-error vectors in a block center are directed to opposite side in relation to vectors located on the edges of a block. In this case it is recommended to check coordinate system selection (to consider the curvature of the Earth) and check interior orientation (to consider distortion).

If there is a big *systematic* XY-error in a block after adjustment, vectors of XY errors are directed radially from block center – the block is compressed in one direction and stretching of the block in perpendicular direction. In this case it is recommended to check for stretching/compression of images in one direction.

If the adjustment was performed by *independent strips* and *independent stereopairs* method, when there was set small weight of equations on GCP (approximately up to 0.01 and less), the block will be compressed.

If the block was adjusted by *bundle adjustment* method, it will be not compressed.

12.2.4. Control of bundle adjustment errors

When perform adjustment by *bundle adjustment method* or import of adjustment results from external software, it is recommended to set in the **Parameters** window on the **Report** tab:

- in the **Tie residuals** section set the **from mean value** checkbox;
- in the **Include in the report** section it is recommended to set the **Residuals**, **on stereopairs**, **include singles** checkboxes.

If *bundle adjustment* method was used to adjust block of images, acquired by long-focus camera or which have images overlap coefficient that exceeds 65%, then when the focal length or images overlap coefficient increase there is a reducing of survey basis/height ratio, in that way the Z-errors on GCP are reduced.

When the adjustment was performed by the *independent stereopairs method*, so reducing of survey basis/height ratio results in increasing of Z-errors on GCP.

When perform adjustment by *bundle adjustment* method Z-error on GCP transforms into Z-error on tie points. In the report Z-error on GCP is displayed in the **Tie point residuals (from mean value)** section.

When perform adjustment by *bundle adjustment* method error on tie points, which coordinates are measured on a single stereopair, in some cases is defined by vertical parallax residual and difference of distances to projection centers of two stereopair images on tie points. In the absence of adjustment blunders, the tie points residual tends to zero and is negligible.

13. Special aspects of airborne blocks adjustment in the system

13.1. Use the coordinates of projection centers

During adjustment with specified projection centers coordinates it is recommended to use *Cartesian* coordinate system (for example, WGS-84).

When perform adjustment with specified projection centers coordinates it is not recommended to use local coordinate system, which takes into account the curvature of the Earth approximately.

During adjustment without projection centers using local coordinate system it is not recommended to consider as precise images exterior orientation parameters obtained by the adjustment. When using a local coordinate system occurs a discrepancy between the Z and XY coordinates of the projection centers, as well as between the angular elements of exterior orientation.

13.2. Survey with big images overlap

The main feature of a survey with big images overlap (more than 70%) is that survey basis to height ratio is small for stereopairs, composed by neighbor images of strip. Therefore, the value of height error on points measured on these stereopairs exceeds plane errors in several times. However, at that 100% of block area is covered by overlaps of three and even more images of a strip. In stereopairs composed by images taken as next nearest (one per 2, 3, depending on overlap size), the survey basis to height ratio is big enough like during usual survey with 60% overlap, that allows to obtain small height error.

The best way of processing of such images blocks depends on kind of output production.

If the end production is orthomosaic creation using exterior DEM, perform the following actions:

1. Perform the whole block processing.
2. Measure coordinates of each point (tie, GCP, check) on all images of a strip, where this point is displayed.
3. Perform adjustment *using bundle adjustment* method.
4. In adjustment report it is recommended to consider only errors on images and errors on GCP and check points shown in the Images mode of working window.

If it is necessary to produce 3D vector objects or DEM, it is recommended to reduce number of images in such a way that images overlap in resulting block will be close to 60%, and then process this block in a usual way. It is recommended to perform such images reducing when images overlap is not less than 75 80%.

In order to evaluate images reducing coefficient, use the following expression:

$(40/(100-k))-1,$ where *k* – images overlap in percent.

Analyze the results:

- final value equals 0 – it is recommended to process all images in strips;
- final value equals 1 – prior processing it is recommended to reduce number of images and involve next *second* image;
- final value equals 2 – prior processing it is recommended to reduce number of images and involve next *third* image;

In order to create orthomosaic using external DEM and 3D vector objects or DEMs choose one of the following ways:

- prior to block processing reduce number of images in strips in such a way that images overlap in resulting block will be about 60%;
- split a block into two subblocks (full and reduced). Then adjust full block and import the adjustment results into the reduced block. Use the full block for orthomosaic creation, and the second one for building 3D vector objects or DEMs.

13.3. Survey by long-focus cameras

The main feature of survey performed by long-focus cameras is that resulting images are rectangles with considerable difference between width and height.

To obtain 3D vector objects or DEMs it is not recommended to use survey performed by long-focus cameras, since considerable height errors occur during the project processing.

In order to decrease elevation errors on images when perform survey by long-focus camera, perform the following actions:

- when possible, turn a camera in such a way, that image long side will be oriented along flight;
- specify images overlap equal 60%; in this case survey basis-height ratio will be maximal and therefore height errors during block adjustment will be minimal;
- place and measure interstrip ties in “zigzag” line, if used geodetic network is not dense enough.

13.4. Survey in different seasons

During processing of images block which contains multi-temporal images, including those acquired in different seasons, there is a problem of tie points measurement.

If images strips were acquired in different seasons, then during tie points measurement in image areas, where interstrip stereo visualization is impossible, it is recommended to measure a tie point on the same object individually in each strip. When measuring tie points on the ground level it is necessary to consider a refinement on height difference of grass cover, which covers an object footing.

In images strips acquired in different seasons, it is recommended to measure tie points on artificial objects (power lines pillars, buildings, roads).

13.5. Survey of forested areas

During processing of images block which contains huge forested areas there is a problem of tie points measurement.

When processing such a survey a residual of neighboring strips exceeds an error that caused by incorrect point positioning. Adjustment accuracy in areas with continuous forest cover and in neighboring areas may be impaired.

If it is impossible to exclude densely forested areas from images block processing, it is recommended to measure tie points on artificial objects (power lines pillars, buildings, roads).

13.6. Bundle adjustment

During *bundle adjustment* operation in the Stereopairs mode of working window occurs deviation from “mean” adjusted position of interstrip ties points by elevation on different stereopairs to the same side. Height deviation is determined by the X-parallax on inter-strip tie points located in stereopairs formed by images of different strips.

During adjustment using *independent stereopairs method* a deviation from “mean” adjusted position by elevation doesn’t occur.

13.7. Tie points measurement on lengthy objects boundaries

If the boundary or its vicinity has no any other objects that are located along the boundary, that are crossing the boundary, common irregular background or boundary curvature, it is not recommended to measure a tie point in the boundary vicinity.

Lengthy objects boundaries – boundaries of objects and objects themselves: roads (tracks), arable lands (consisting of parallel furrows) and other similar objects.

14. Data export and import

14.1. Central projection

14.1.1. Export of initial data

The system provides opportunity to perform export of source data for further adjustment in third party software. The system allows to export data to *AeroSys* software format, as well as to *PAT-B* format.

Export or import of adjustment data is *only* possible in projects of central projection images.

For source data export perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Export options** window opens.

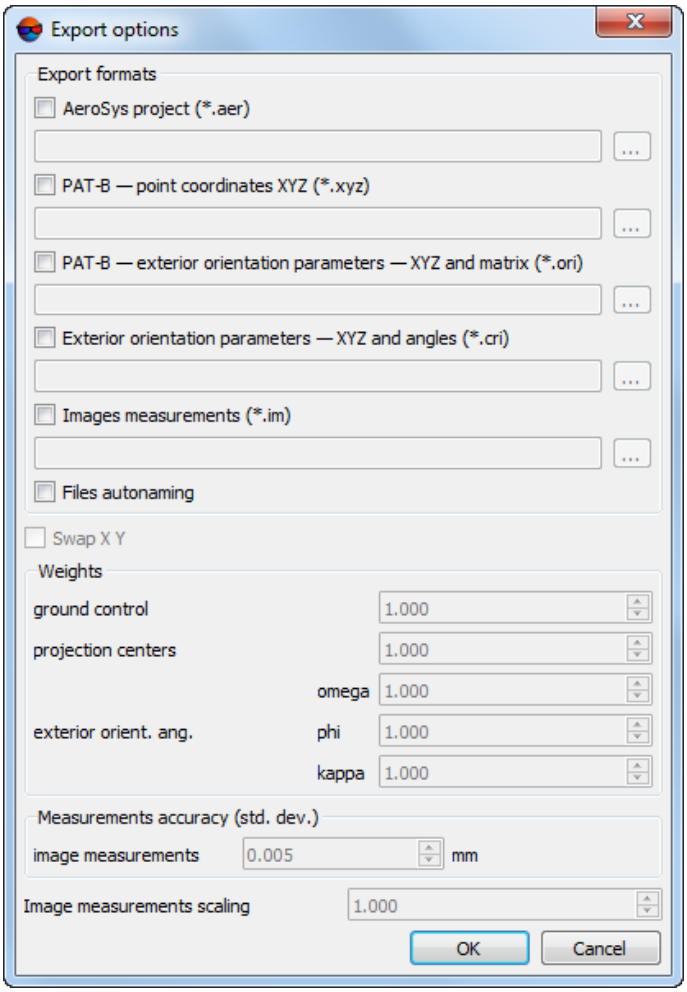


Fig. 49. Export parameters

2. In the **Export formats** section set one or multiple formats checkboxes, to which it is necessary to export the data:

   - **AeroSys project** – is used to perform further adjustment in the *AeroSys* program. Files of this format has the `*.aer` extension;

     During export to *AeroSys* format all measurements of the system project are exported to *AeroSys* project, see the official web-site of *AeroSys* company.

   - The **PAT-B (point coordinates XYZ)** format – is used to perform further adjustment in third party software. File of this format contains coordinates of measured points in meters. Files of this format has the `*.xyz` extension;

   - The **PAT-B (exterior orientation parameters – XYZ and matrix)** format – is used to export coordinates of images projection and matrix of angular exterior orientation parameters. Files of this format has the `*.ori` extension;

- **Exterior orientation parameters – XYZ and angles** – is used to export coordinates of images projection and angular exterior orientation parameters. Files of this format has the `*.cri` extension;

- **Images measurements** – is used to perform further adjustment in third party software. File of this format contains coordinates of measured points in pixels. Files of this format has the `*.im` extension.

3. [optional] In order to swap coordinate system (left/right) during adjustment import, in the **Coordinates** section set the Swap X Y checkbox.

   If the **Swap X Y** checkbox is off, the initial data will be imported in the right coordinate system. Otherwise, in the left one.

4. Click the ... button. The **Destination file** window opens.

5. Choose a folder to place a file in *Windows* file system.

6. Specify file name where to export adjustment results.

   When input a name of some file the same file name and path is set for all selected formats automatically.

7. [optional] To cancel automatic specifying of the same name for all selected formats, set the **Files autonaming** checkbox off.

8. [optional] To correct an accuracy of GCP geodetic coordinates, projection centers and exterior orientation parameters, edit weight values of these parameters in the **Weights** section (default value is 1). In output file a value of accuracy will be divided by specified weight.

9. [optional] To measure a priory RMS accuracy of points measurements on images, set the **image measurements** value in mm in the **Measurements accuracy (std.dev.)** section.

   This is used for less quality source images. By default it is set 0.5 pixel (0.005 mm) value for measurements, obtained from scanned images acquired by precisely calibrated camera.

   Besides measurements (points coordinates on images, geodetic coordinates of GCP's, exterior orientation parameters), the a priory accuracy of these measurements is written to the exported files as well.

10. [optional] In order to export adjustment results in necessary measurement units (in microns, for example), in the **Image measurements scaling** input field input a coefficient which all measurements will be multiplied by.

11. Click OK to complete the export operation.

14.1.2. Import of adjustment results

The system provides opportunity to perform import of adjustment results obtained using third party software.

Export or import of adjustment data is *only* possible in projects of central projection images.

For import of adjustment results obtained in the *AeroSys* software or other software packages, it is recommended to choose *Cartesian coordinate system* for the system project, otherwise, XY and Z residuals may occur in coordinates of images projection centers.

To import adjustment results, obtained in the *AeroSys* software perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Adjustment import** window opens.

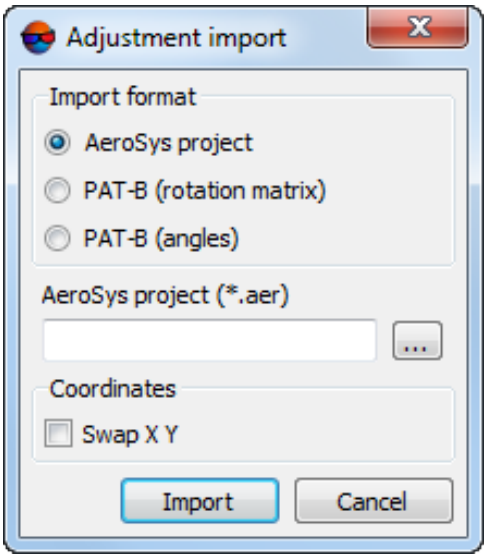


Fig. 50. Parameters of import from AeroSys project

2. In the **Import format** section set the **AeroSys project** format.
3. Click the button. The **Open AeroSys project** window opens.
4. Specify a name and path of the AeroSys project in *Windows* file system (file with `*.aer` extension).
5. [optional] In order to change coordinate system during the adjustment import, in the **Coordinates** section set the **Swap XY** checkbox.

If the **Swap X Y** checkbox is off, the initial data will be imported in the right coordinate system. Otherwise, in the left one.

6. Click **Import** to complete import operation from AeroSys project to the system.

To import adjustment results from file, which contains coordinates of images projection centers and matrix of angular exterior orientation parameters, perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Adjustment import** window opens.

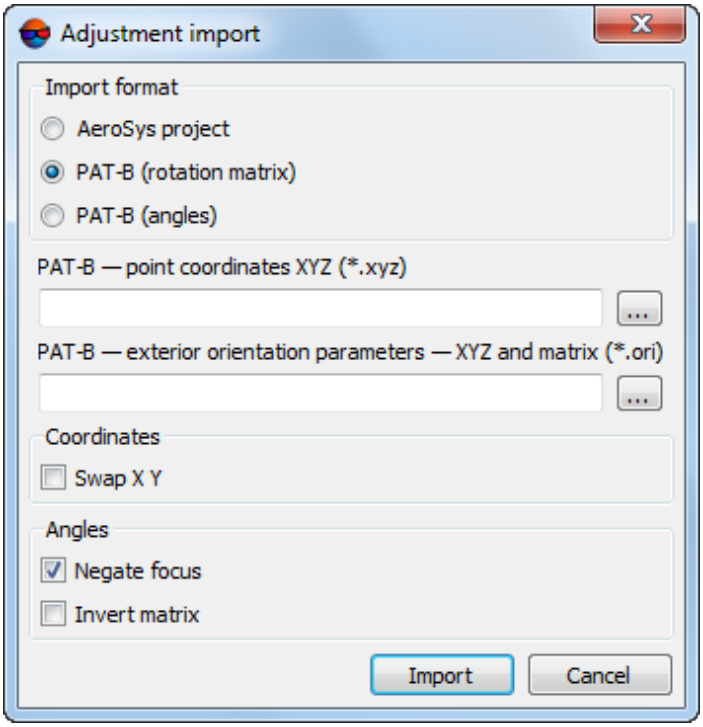


Fig. 51. Parameters of import from PAT-B format

2. In the **Import format** section set the **PAT-B (rotation matrix)** format.

3. In the **PAT-B – point coordinates XYZ** field click the button. The **Open PAT-B file – point coordinates** window is opened.

4. Specify a name and path of the file with **points coordinates** in Windows file system (file with `*.xyz` extension).

5. In the **PAT-B – exterior orientation parameters – XYZ and matrix** field click the button. The **Open PAT-B file – exterior orientation parameters** window opens.

6. Specify a name and path of the file with **points coordinates** in Windows file system (file with `*.ori` extension).

7. [optional] In order to swap coordinate system (left/right) during adjustment import, in the **Coordinates** section set the **Swap X Y** checkbox.

   If the **Swap X Y** checkbox is off, the initial data will be imported in the right coordinate system. Otherwise, in the left one.

8. [optional] In order to change a direction of coordinate system if the coordinate systems directions are mismatched, in the **Angles** section set the **Negate focus** checkbox on.

9. [optional] In order to invert a matrix of angles rotation, set the **Invert matrix** checkbox on in the **Angles** section.

10. Click the **Import** button to complete import from PAT-B format to the system.

To import adjustment results from file, which contains coordinates of images projection centers and exterior orientation angles, perform the following actions:

1. Click the button on the **Adjustment** toolbar. The **Adjustment import** window opens.

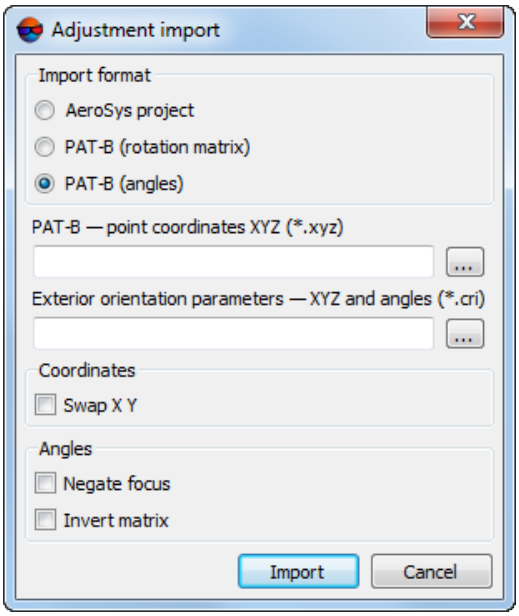


Fig. 52. Parameters of import from PAT-B format

2. In the **Import format** section select the **PAT-B (angles)** format.

3. In the **PAT-B – point coordinates XYZ** field click the ... button. The **Open PAT-B file – point coordinates** window is opened.

4. Specify a name and path of the file with **points coordinates** in Windows file system (file with `*.xyz` extension).

5. In the **Exterior orientation parameters – XYZ and angles** field click the ... button. The **Open exterior orientation parameters file – XYZ and angles** window opens.

6. Specify a name and path of the file with **points coordinates** in Windows file system (file with `*.cri` extension).

7. [optional] In order to swap coordinate system (left/right) during adjustment import, in the **Coordinates** section set the **Swap X Y** checkbox.

   If the **Swap X Y** checkbox is off, the initial data will be imported in the right coordinate system. Otherwise, in the left one.

8. [optional] In order to change a direction of coordinate system if the coordinate systems directions are mismatched, in the **Angles** section set the **Negate focus** checkbox.

9. [optional] In order to invert a matrix of angles rotation, set the **Invert matrix** checkbox in the **Angles** section.

10. Click the **Import** button to complete import from PAT-B format to the system.

14.2. Scanner projects

14.2.1. Export of refined RPC-coefficients

The system provides the possibility to export refined RPC-coefficients after adjusting a scanner project. Due to using GCP/tie points during the adjustment, RPC-coefficients are refined and can be used along with project images in third-party software packages.

To export refined RPC-coefficients, perform the following:

The export of refined RPC-coefficients is possible only for a scanner project adjusted using RPC-coefficients (see the “RPC method” section in the “Block adjustment” User Manual).

1. Choose **Orientation › Export images orientation to RPC**. The **Export to RPC** window opens:

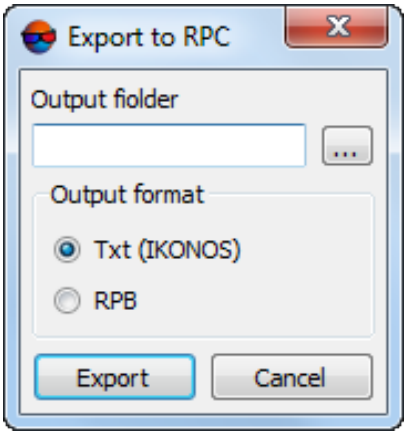


Fig. 53. The Export to RPC window

2. **Select destination folder for RPC export** and click the **Select folder** button to start exporting refined RPC-coefficients.

3. Select the **output format**:

   - `*.txt` (**IKONOS**) – RPC-coefficients may be exported for all project images to a folder specified by a user. RPC-coefficients are exported for each image to a separate text file of the *IKONOS* format (this format is the most widely used among all existing formats of RPC-coefficient recording/transmitting).

   - **RPB**.

4. If the export is successful, an appropriate information message will appear. If refined RPC-coefficients export is not possible, the system also displays an appropriate information message. In this specified folder a detailed report file `rpc_export_report.txt` is also created.

Exported refined RPC-coefficients can be used along with the project images both in third-party software packages or in *PHOTOMOD* program.

Appendix A. Exterior orientation angular systems

The angular exterior orientation parameters are calculated and included to the report as ’omega-phi-kappa’ or ’alpha-omega-kappa’ system of angles.

Rotation sequence in ’omega-phi-kappa’ angular system.

a)

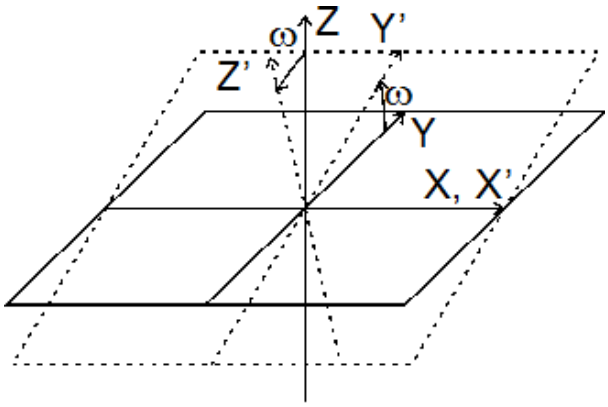


Fig. A.1. Rotation about X-axis at a positive value of “omega” angle

b)

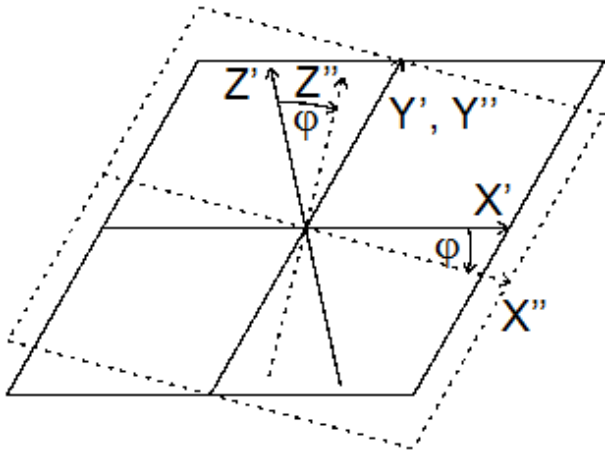


Fig. A.2. Rotation about Y-axis at a positive value of “phi” angle

c)

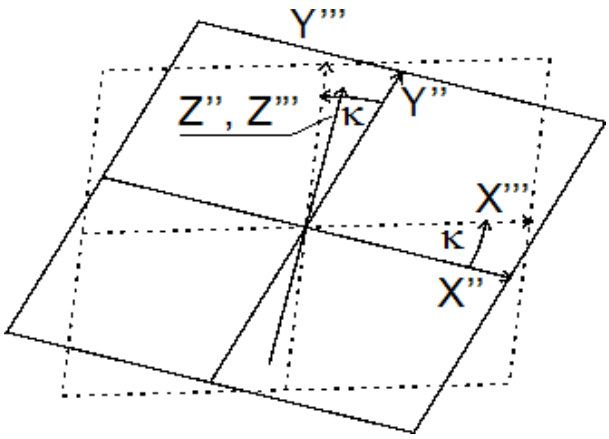


Fig. A.3. Rotation about Z-axis at a positive value of “kappa” angle

Rotation sequence in ’alpha-omega-kappa’ angular system.

a)

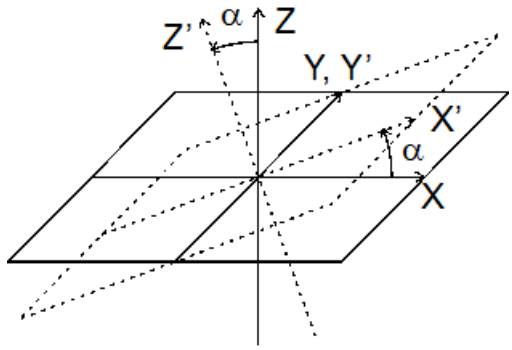


Fig. A.4. Rotation about Y-axis at a negative value of “alpha” angle

b)

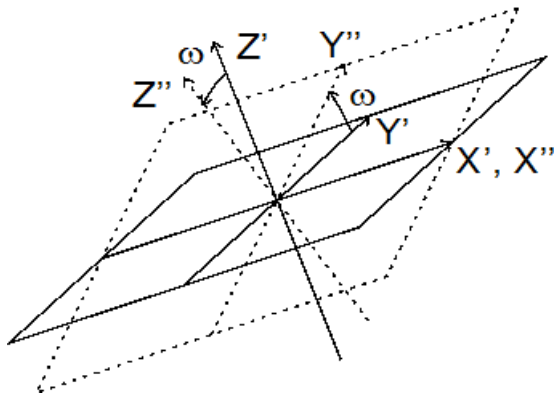


Fig. A.5. Rotation about X-axis at a positive value of “omega” angle

c)

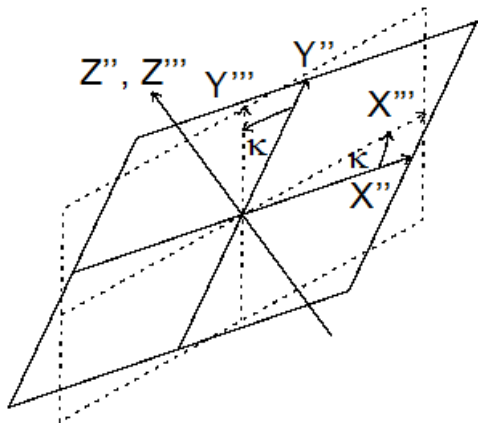


Fig. A.6. Rotation about Z-axis at a positive value of “kappa” angle