Digital Photogrammetric System

PHOTOMOD

Version 6.0.2

USER MANUAL

Block adjustment

RACURS

Table of Contents

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.

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
📇	allows to load or restore current status of a block (load adjustment results after reloading project)
🖼	allows to open window used to setup parameters of block adjustment (see Section 7 and Section 8)

Buttons	Function
$\sqrt{\alpha}$	allows to start the adjustment procedure
🖹	allows to open window with results of block adjustment (see Section 10)
🖫	allows to save results of block adjustment in order to pass to the next stage of project processing in the system
🗘	allows to reset block to initial state
🗗	[only for central projection] allows to export adjustment results for further adjustment in third party software
🗗	[only for central projection] allows to import adjustment results obtained using third party software
××	allows to display a window of displaying triangulation points settings
🗛	allows 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
𝔖	allows to show/hide the window 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)
🔵	allows to show/hide the **Point attributes** window with information about selected point and possibility to manage a type of points (see Section 5.5)
🔺	allows 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 the window.
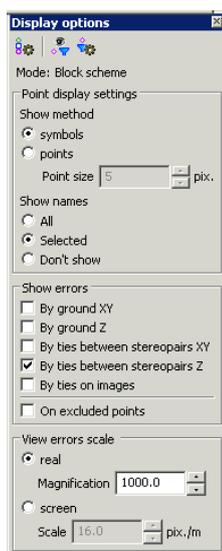
Fig. 1. Parameters of triangulation points display

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.

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.
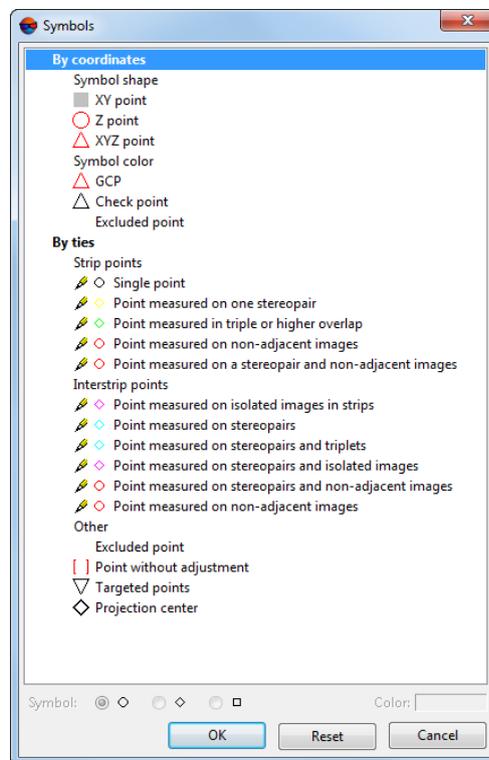
Fig. 2. The "Symbols" window

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 and in the **Triangulation points** table. The **Point filter** window is used for that.

To open the **Point filter** window, in the **Display options** window click the 🔧 button.
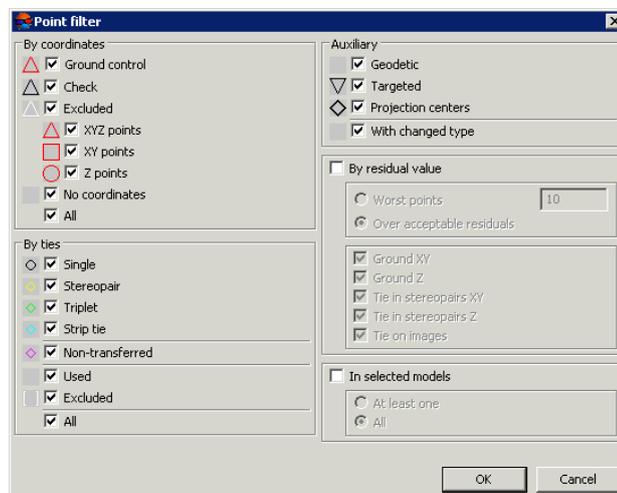
Fig. 3. The "Point filter" window

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;

○ **no coordinates** – 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 parameters **Ground XY**, **Ground Z**, **Tie XY**, **Tie Z**.

> 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.

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 ![icon] button to select points to be highlighted. The **Select points** window is opened.
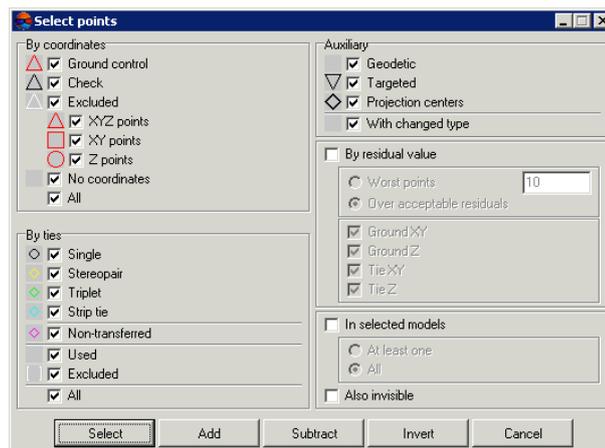
Fig. 4. The "Select points" window

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;

  ○ **no coordinates** – 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 parameters **Ground XY**, **Ground Z**, **Tie XY**, **Tie Z**.

  > 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.
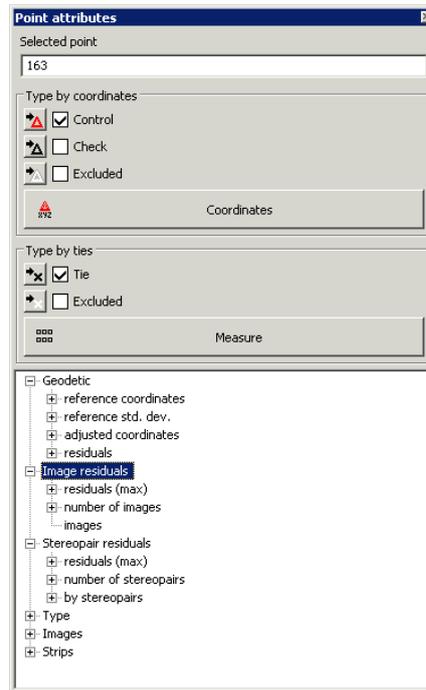
Fig. 5. The "Point attributes" window for selected point

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:

- ![icon] – allows to set selected point as a GCP;

- ![icon] – allows to set selected point as a check point;

- ![icon] – allows to exclude selected check point or GCP from further adjustment;

- ![icon] – allows to add excluded tie point to adjustment;

- ![icon] – 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 change coordinates of selected GCP, click the **Coordinates** button in the By coordinates section. ![icon] **Coordinates** button. The **Triangulation points** window

opens. Double-click on point name allows to open the **Points measurement** module to edit point's position (see the "Aerial triangulation" User Manual).

In order to change coordinates of selected tie point, button in the **By ties** section click the ▦ **Measure** button. The **Points measurement** window opens where the tie point is displayed on block images (see Section 11).

Section in the lower part of the **Point attributes** 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).

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 ![icon] button on the **Adjustment** toolbar or choose **Window › Triangulation points coordinates** .

Fig. 6. The "Triangulation points" window

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

- ![icon] – allows to set on/off the filter of triangulation points display;

- ![icon] – allows to setup the filter of triangulation points display;

- ![icon] – allows to display all/selected on a block scheme points in the table;

- ![icon] – is used to search for an image by name (part of name);

- ![icon] – allows to display GC/tie points with initial coordinates (see the 'Aerial triangulation" User Manual);

- ![icon] – allows to display triangulation points with coordinates obtained after adjustment;

- ![icon] – allows to display only errors.

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.

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.
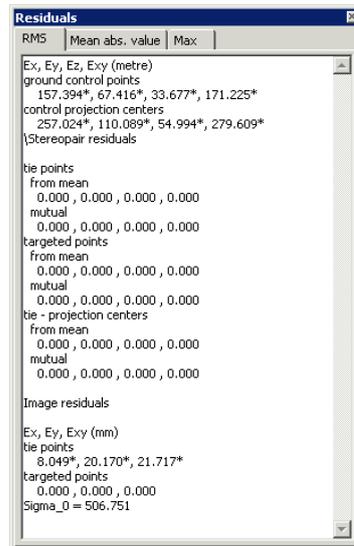
Fig. 7. The "Residuals" window

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).

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.
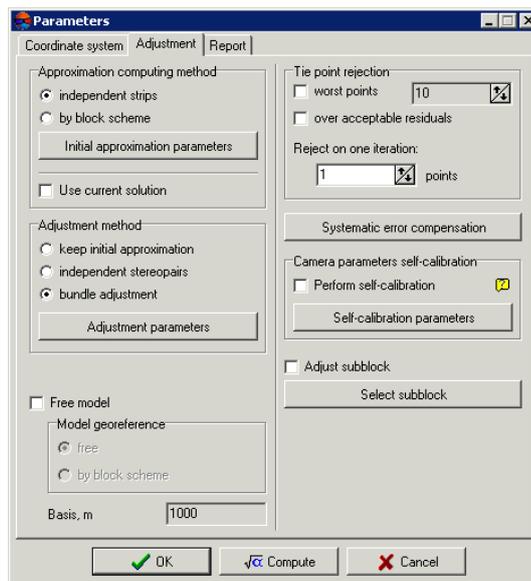
Fig. 8. Parameters of adjustment of central projection images block

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. 9. 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.
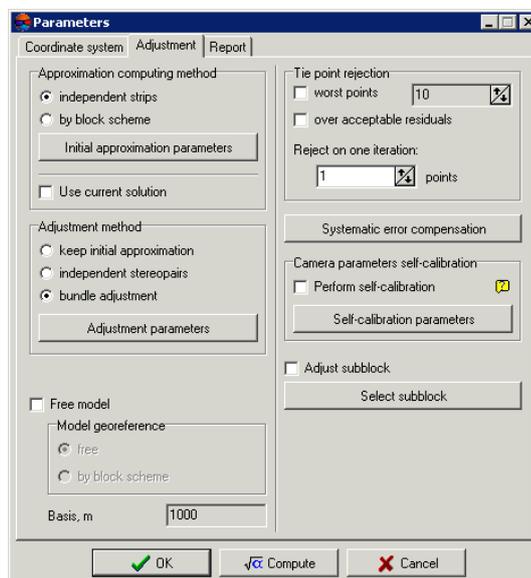
Fig. 10. Parameters of adjustment

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.

        🎓   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 the **Tie point rejection** section specify conditions of triangulation points filtering:

- **worst points** – to filter specified number of tie points with maximal residuals;

- **over acceptable residuals** – to filter tie points where residuals values exceed preset threshold (on the **Report** tab).

8. In the **Reject on one iteration** input field specify number of points to be rejected (in accordance with specified filtering conditions) on each step of iterative procedure of adjustment.

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

10. [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.

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

12. [optional] The **Consistency check** checkbox allows to check availability of all source data that are required to adjustment. If any data is not available, the error message displays and adjustment process doesn't start.

> ⚠ If the **Approximation computing method** *by a block scheme* and the *bundle adjustment method* were chosen, consistency check doesn't perform regardless of the checkbox.

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

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.

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.
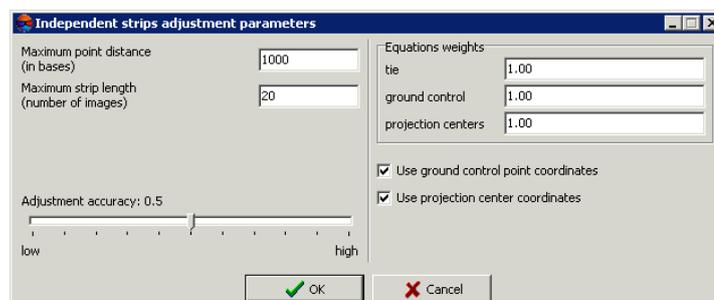
Fig. 11. The "Independent strips adjustment parameters" window

5. Specify the **Maximum points distance (in bases)** parameter. The parameter is used to process close range projects, where points with big X-parallax difference is measured.

    > Applying this parameter results in automatic excluding from adjustment on each stereopair those points, distance from which to projection centers exceeds specified distance in bases. For example, ia a stereopair basis is 10 meters, and predefined value of maximal distance is 100 meters, then the system will exclude the points which distance from projection centers is more than 1000 meters.

    > It is recommended to set the value of the parameter not more than 100 bases, since when points with distance exceeding 100 bases of survey are considered in adjustment, independent strips (or stereopairs) method may disagree or bring to result with big errors.

    > If there are no blunders in measurements, decreasing of the **Maximum points distance (in bases)** value results in decreasing of RMS on a block. Too small value results in breaking of adjustment operation and shows warning about error due to lack of tie points in triplet.

6. 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.

7. 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.

8. [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"*.

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

10. [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 ![icon] 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.
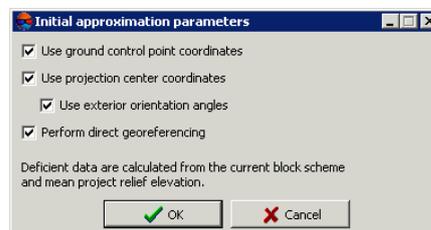
Fig. 12. The "Initial approximation parameters" window

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.
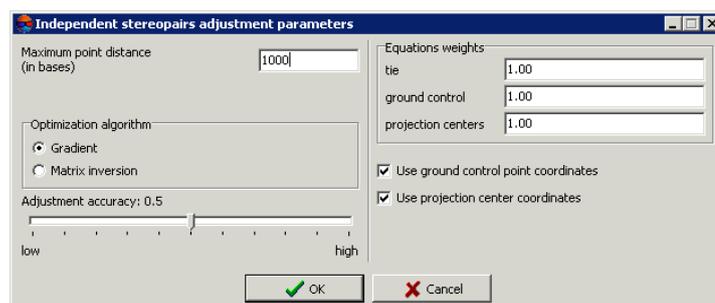
Fig. 13. The "Independent stereopairs adjustment parameters" window

5. In the **Optimization algorithm** section choose one of the following algorithms:

- **gradient** (by default);

- **Matrix inversion**.

> Method of matrix inversion was used in previous versions of the system and it is developed for relatively small blocks of images (up to 500 images).

6. Setup parameters of the *independent stereopairs method* and click OK. Parameters of the *independent stereopairs method* are setup right in the same way as parameters of independent strips method.

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.
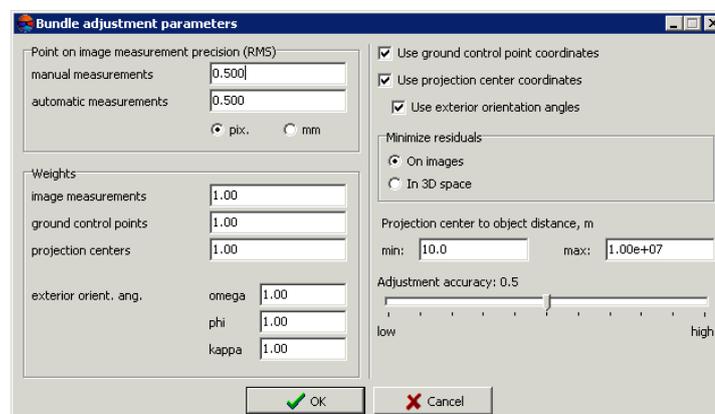
Fig. 14. The "Bundle adjustment parameters" window

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. In the **Minimize residuals** section choose one of the following options:

   • in order to obtain more accurate result, select residuals minimization **on images**;

- in order to obtain less accurate, but more robust result, select residuals minimization **in 3D space**.

11. The **Projection center to object distance, m** input field is used to specify parameters to filter points with blunders: minimal and maximal distance from projection centers to objects in meters.

> For central projection images taken by aerial and space cameras it is recommended to use default values. For central projection images acquired during close range survey, as well as for images of space objects taken from big distance it is recommended to specify the **Projection center to object distance, m** value with accuracy up to order.

12. [optional] Use the **Adjustment accuracy** slider to specify value of relative adjustment accuracy, when it is reached the iteration process of adjustment is completed.

13. 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.
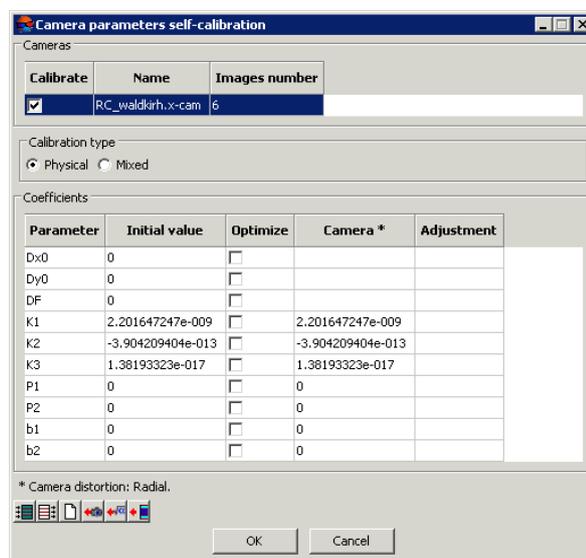
Fig. 15. The "Camera parameters self-calibration" window

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

6. Click the ▣ button to copy coefficients from the camera passport.

7. 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).

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

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

10. Click the $\sqrt{\alpha}$ **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 sat-

isfying results pass to the next step, otherwise, change initial values and/or a set of optimization parameters and adjust the block once more.

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

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

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

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

15. Click the $\sqrt{\alpha}$ button **Settings** on the **Adjustment** toolbar. Block will be adjusted considering new results of interior orientation.

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.
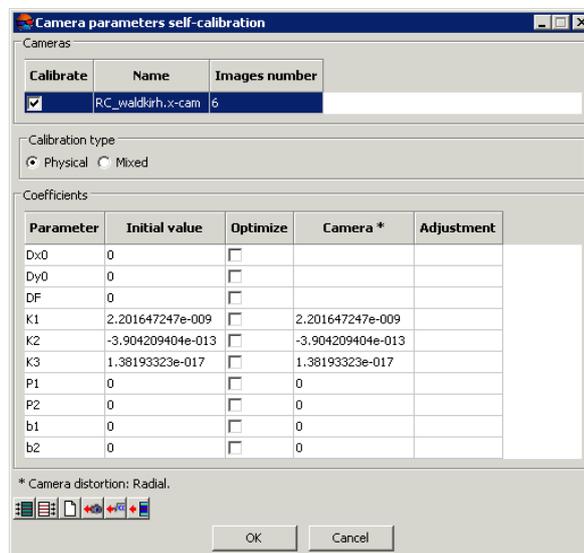
Fig. 16. The "Camera parameters self-calibration" window

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.

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` – coefficients of radial distortion;

  ○ `P1, P2` – 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, click on the , after that the "+" sign is shown in the column. In order to unselect optimization parameter it is necessary to use one more mouse click;

- **Camera** – initial data of camera, specified on interior orientation step in the **Camera** window (see **Orientation › Manage cameras**);

> 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.

> If table distortion data was setup during step of camera parameters input, so in the **Camera** column distortion coefficients are shown for this camera. The coefficients are obtained as a result of approximation of initial table distortion data using the following formula:

$$x_{corr} = x - k_1 xr^2 - k_2 xr^4 - k_3 xr^6 - P(2x^2 + r^2) - 2P_2 xy - b_1 x - b_2 y;$$
$$y_{corr} = y - k_1 yr^2 - k_2 yr^4 - k_3 yr^6 - P(2y^2 + r^2) - 2P_2 xy - a_1 x - a_2 y;$$
$$r^2 = x^2 = y^2,$$

where:

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

k1, k2, k3 – coefficients of radial distortion;

p1, p2 – coefficients of tangential distortion;

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

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.

- **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.
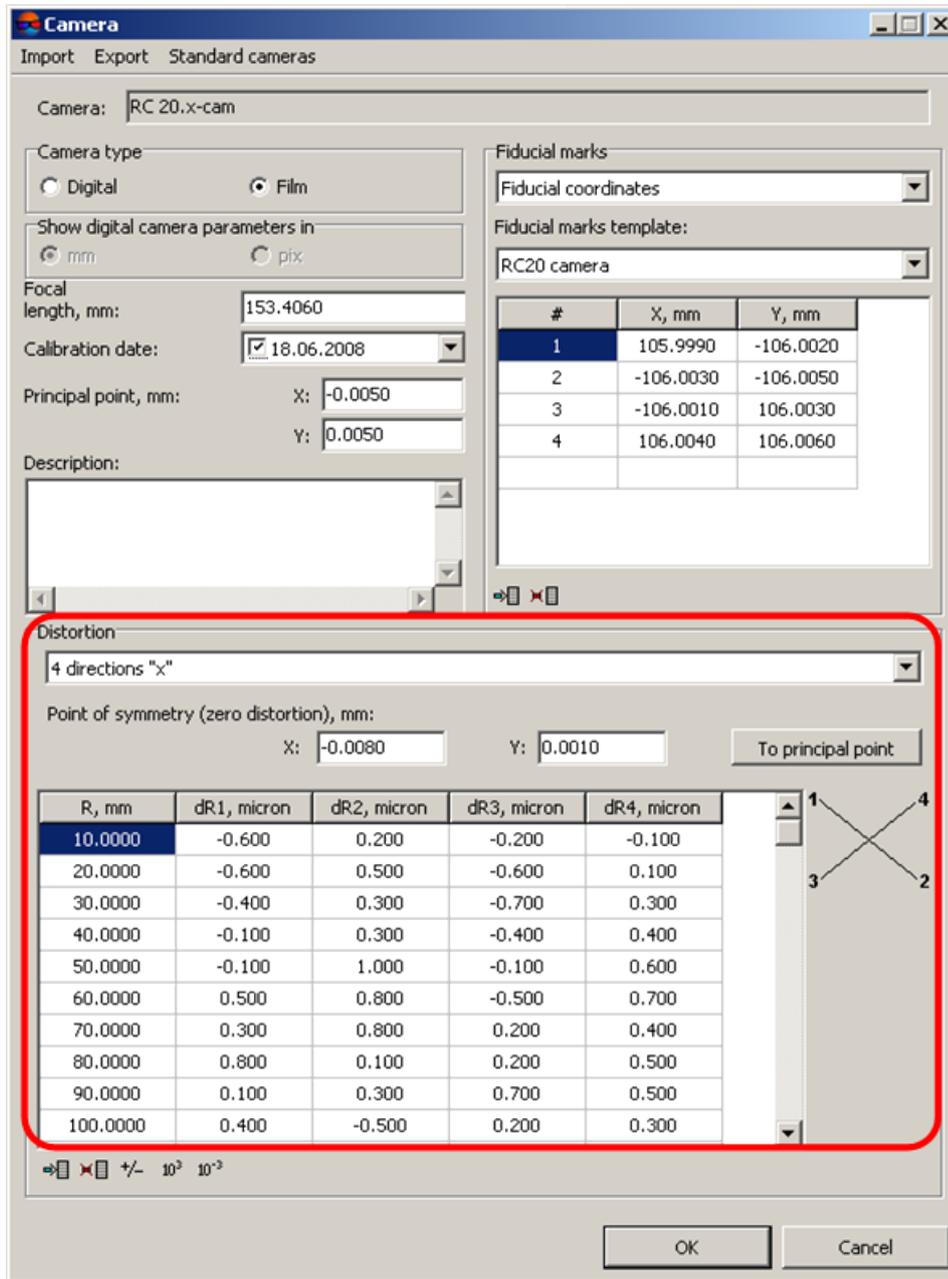
Fig. 17. Initial table data of distortion from camera passport, defined in the "Camera" window during input
of camera parameters step
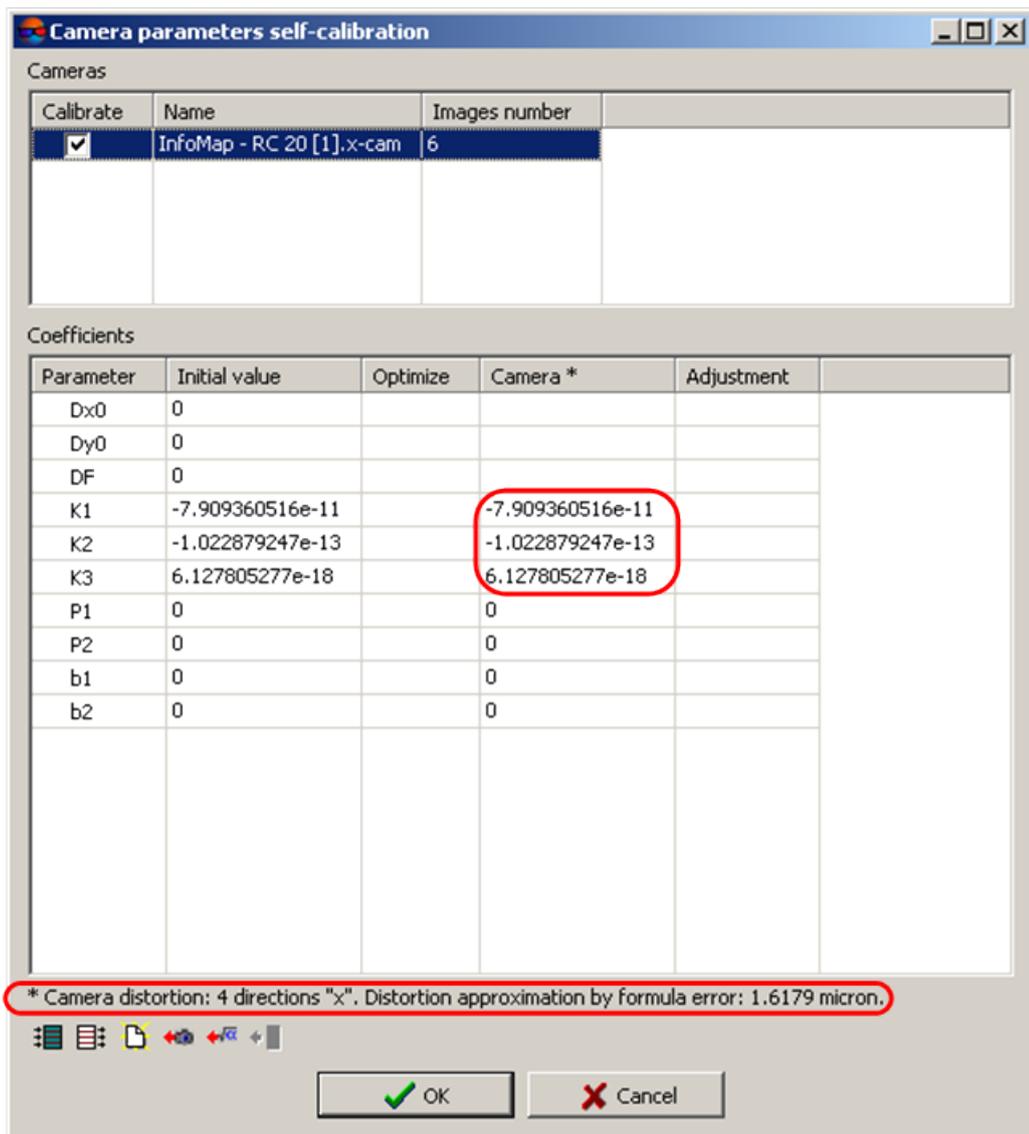
Fig. 18. Distortion coefficients K1, K2, K3 calculated as a result of approximation by formula, and distortion error

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.
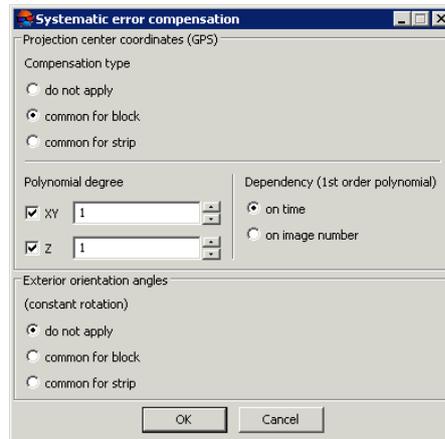
Fig. 19. The "Systematic error compensation" window

The **Projection center coordinates (GPS)** section is used to 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.

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.

In the **Polynomial degree** section the **XY** and **Z** checkboxes allow to specify coordinates to which corrections will be added. The section also contains fields to specify polynomial degree.

> Corrections to projection centers coordinates are calculated using GCP and look like the following:
>
> $\Delta X = G_0 x + G_1 x \quad N$
> $\Delta Y = G_0 y + G_1 y \quad N,$
> $\Delta Z = G_0 z + G_1 z \quad N$
>
> where N – sequence number of image in a block or strip or time in GPS system, which corresponds to a moment when the image was taken (is defined by the **Dependency (1st order polynomial)** parameter), G – polynomial coefficients calculated at adjustment.

When 1-st order polynomial are chosen the G_0, and G_1 coefficients will be used. If 0 order polynomial are used, just the G_0 coefficient is applied, and G_1 will be equaled to zero.

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:

$$\Delta\ \omega = A_\alpha$$
$$\Delta\ \phi = A_\phi\ ,$$
$$\Delta\ \kappa = A_\kappa$$

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.
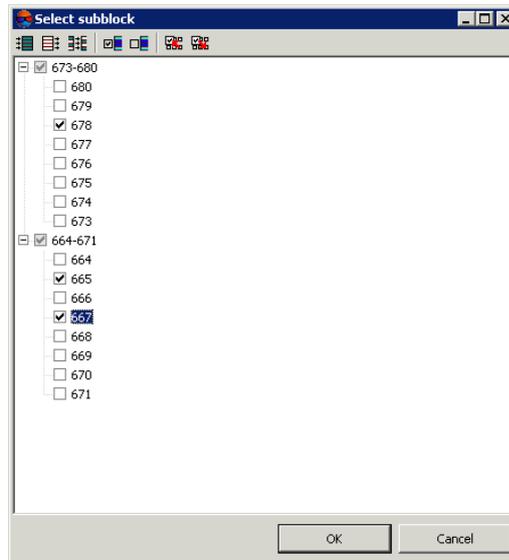
Fig. 20. The "Select subblock" window

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.
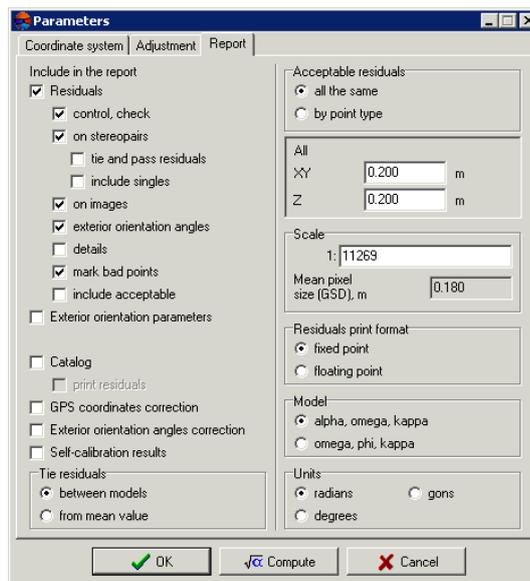
Fig. 21. The "Settings" window

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

1. The parameters group **Include in 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 **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.

4. 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.

5. 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*.

6. 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).

7. The **Angle 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.

8. Adjustment of scanner blocks

8.1. Workflow of scanner block adjustment

At that preliminary parameters setup is required. A set of the parameters depends on method of scanner data processing: rigorous, generic or RPC-method (detailed information about algorithms of space images processing see in the "Project creation" User Manual).

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

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.
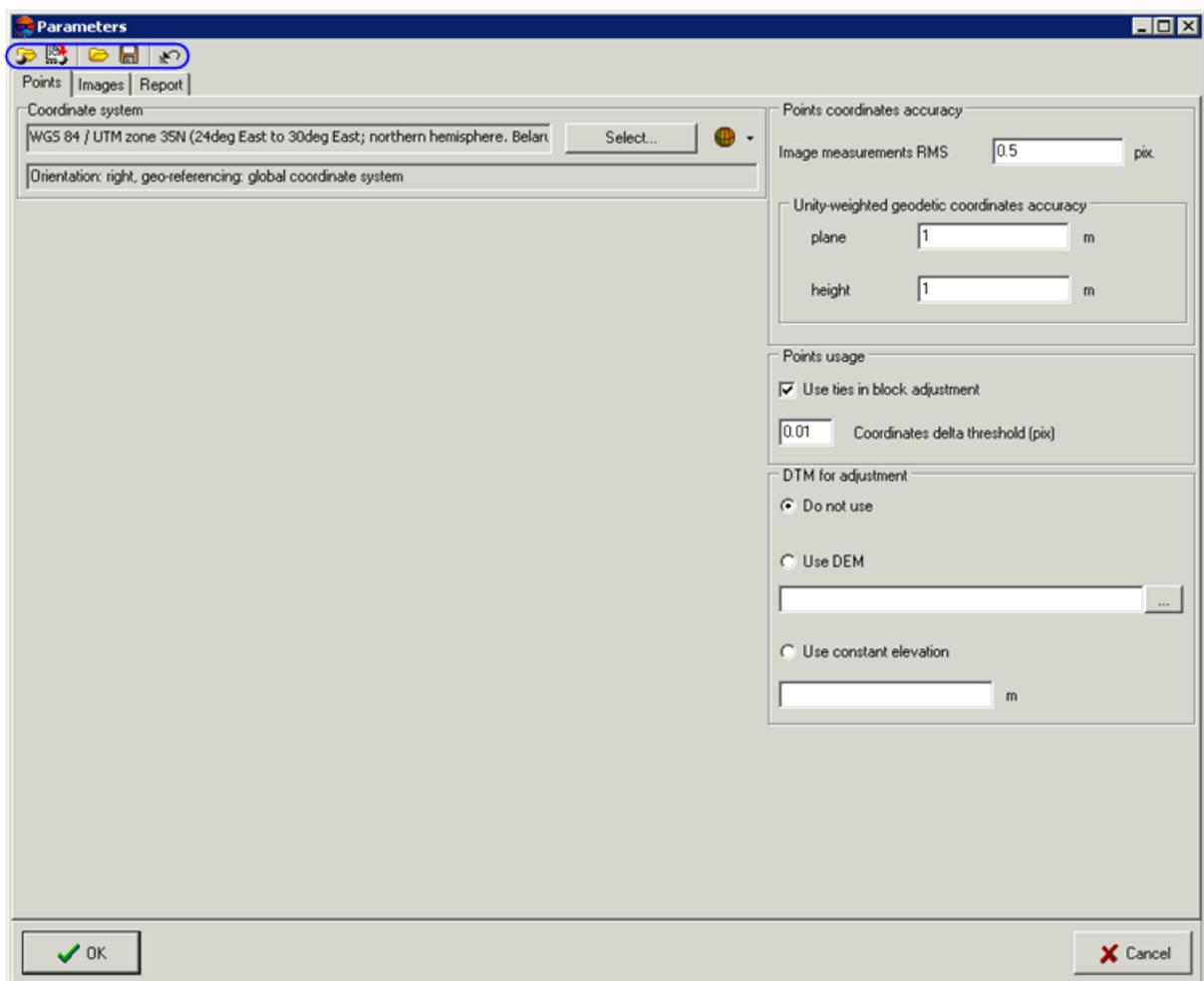
Fig. 22. The "Parameters" window toolbar

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 **Images** 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. After that the system checks parameters settings. If their values are incorrect, the tab containing field with incorrect value becomes active, and the input field gets red. If parameters were specified correctly, the **Parameters** will be closed.

7.   Click the $\sqrt{\alpha}$ 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 Adjust-ment** 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 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.
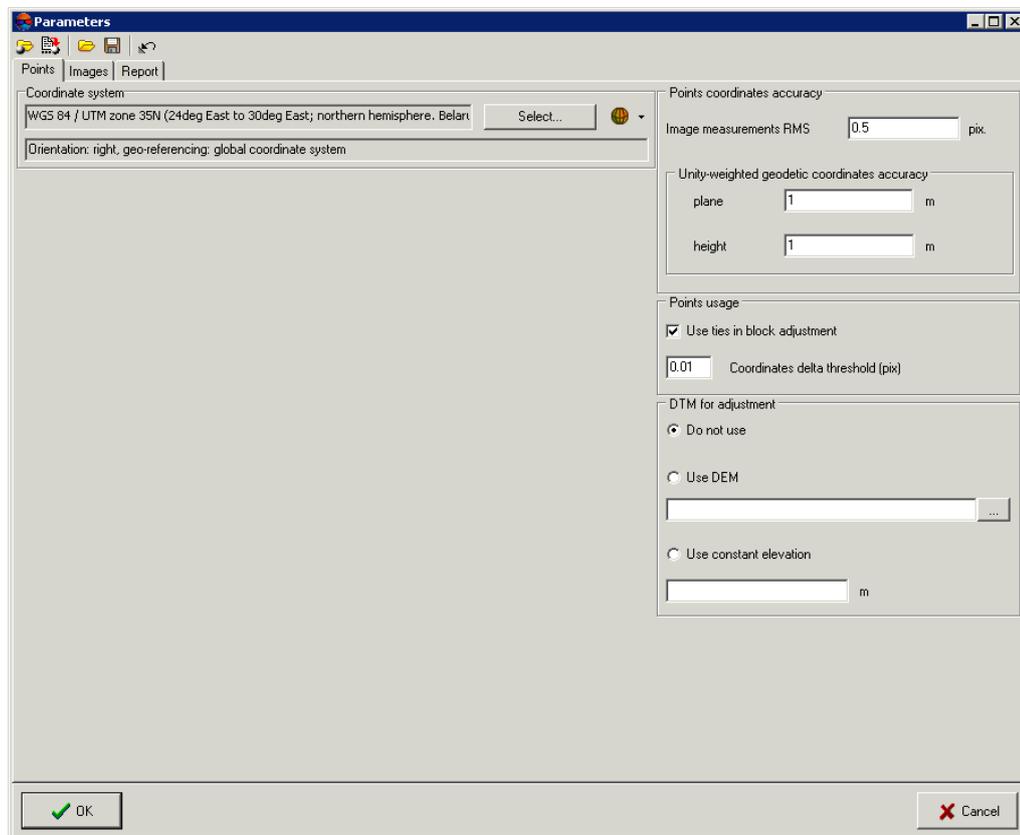
Fig. 23. Parameters of adjustment

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 the "Project creation" User Manual).

• the **Points coordinates accuracy** section is used to specify accuracy of pixel (on image) and geodetic (on ground) points coordinates, included to adjustment:

○ **Image measurements RMS** (pix.) – a priori accuracy of measurements of GCP and tie points on images (if the latter were used for adjustment);

○ **Unity-weighted geodetic coordinates accuracy** – a priori measurement errors of GCP coordinates in **plane** (X,Y) and **height** (Z), which weight equals 1.

> Unity-weighted accuracy of plain and height geodetic coordinates are setup in the same units as those used in project coordinate system.

• the **Points usage** section is used to setup using/excluding tie points in/from adjustment operation (the checkbox is set by default).

> *Coordinates delta threshold* (pix) – minimal difference between point's position in pixel co-ordinates, calculated on adjacent iterations using exterior orientation parameters during adjustment operation. When the parameter is reached, iterative operation is terminated.

> It is recommended to setup this threshold value in range from 0.01 to 0.2 pixel.

• 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 (out from active profile resources);

> The system memorizes the last used DEM .

○ **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.

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.
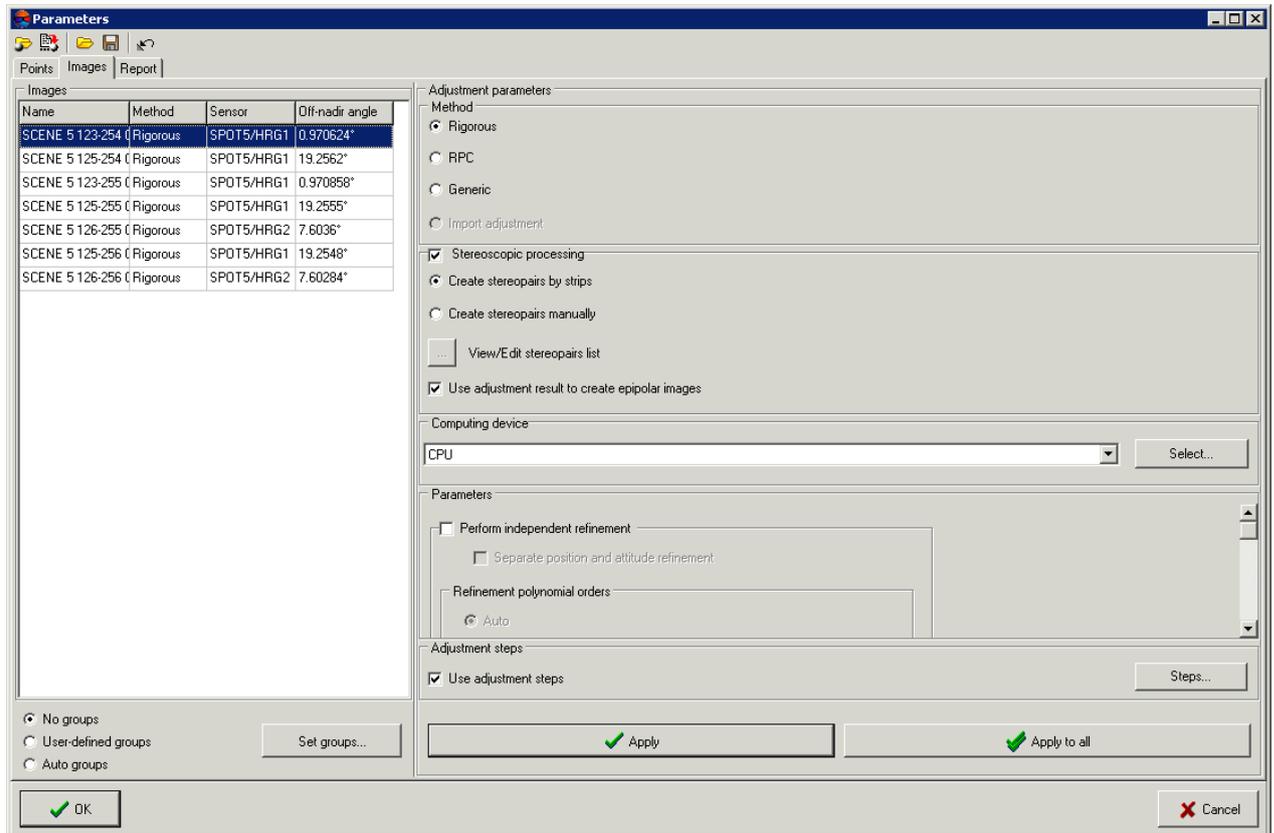
Fig. 24. Parameters of adjustment

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

• in the left part there is the **Images** table, which displays all project images and method of their processing, sensor and off-nadir angle;

• left lower part of the window contains the section 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 8.6).

• the right part of the window contains two following sections:

○ the **Adjustment parameters** section is used to setup parameters of scanner space images adjustment method or to import exterior orientation parameters from metadata of ADS 40/80/100 images;

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

In order to setup adjustment parameters on the **Images** tab perform the following actions:

1. Click the 🖼 **Options** button. The **Parameters** window opens.

2. Choose the **Images** tab.

3. In the **Method** section select adjustment method:

    ☞ If there is sufficient or abundant number of GCP in a project, so it does not matter what method to use, since adjustment results will be almost the same. If there is a few GCP in a project it is possible first to use one adjustment method, and in case of poor adjustment result – another one. About recommended amount of GCP needed for scanner block adjustment see Section 8.6.

    • **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.

4. In the **Stereoscopic processing** section set the **Stereoscopic processing** checkbox to perform adjustment with stereopairs creation.

5. [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.

6. [optional] In order to form stereopairs from block images manually select the **Create stereopairs manually** option and click the **View/edit stereopairs list** button.

7. [optional] 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).

8. In the **Computing device** section select a computing device that will be used for adjustment procedure: *CPU* or *GPU*.

> If working station is equipped with *NVIDIA CUDA* processor, choose the *GPU* option to speed up adjustment procedure (see detailed information on web-site http://www.nvidia.ru/object/cuda_gpus_ru.html).

> ⚠ In case of *GPU* was chosen as an accounting device, but it initialize was failed or it has not enough of computational capability, *CPU* is used automatically.

9. In the **Parameters** section setup adjustment parameters, which set depends on selected method of images processing.

> 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*.

10. [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.

11. [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.

12. Click the **Apply** or **Apply to all** button to apply setup parameters to selected image or to all images of a block correspondingly.

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.
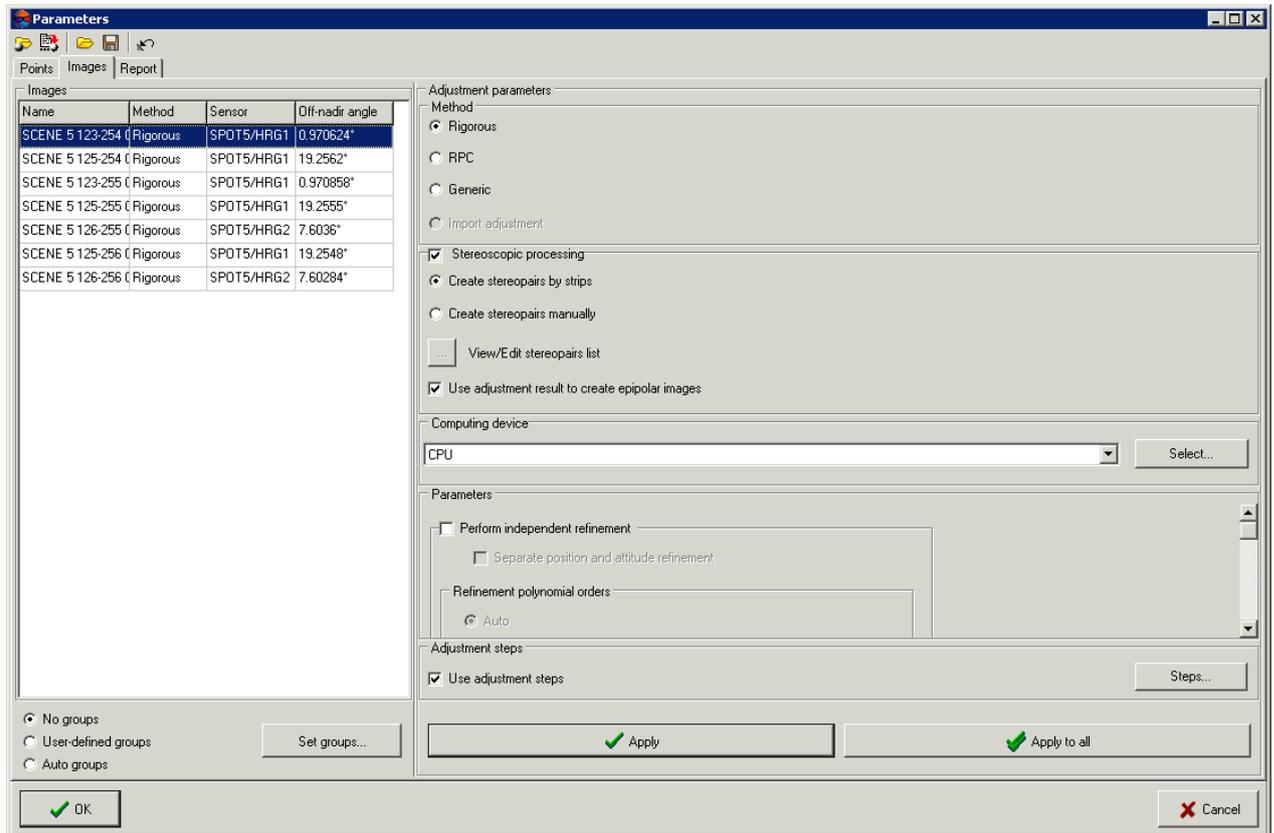
Fig. 25. Parameters of rigorous method of adjustment

The *rigorous* method provides two ways of adjustment:

• **Perform independent refinement** – allows to adjust block images individually (along with applying of polynomial corrections), i.e. each image is adjusted considering just GCP measured on the image, without using ties with other block images;

> Independent refinement is applied to obtain initial approximation for block adjustment or is used as a main operation of single image orientation (in case of excluding this image from block adjustment).

If the **Separate position and attitude refinement** checkbox is set the system applies corrections to linear and angular exterior orientation parameters *by turns*.

• **Involve into block adjustment** (by default) – allows to adjust the whole images block using both GCP and tie points along with applying of polynomial refinements (under condition that the **Use ties in block adjustment** checkbox is set on the **Points** tab).

> To perform correct adjustment by *rigorous* method it is recommended to use default settings.

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	
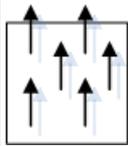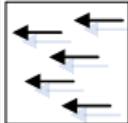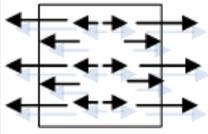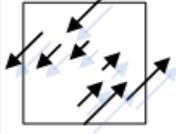
8.3.3. RPC method

When perform adjustment by *RPC method* the system uses RPC coefficients from metadata, obtained from RSD provider.
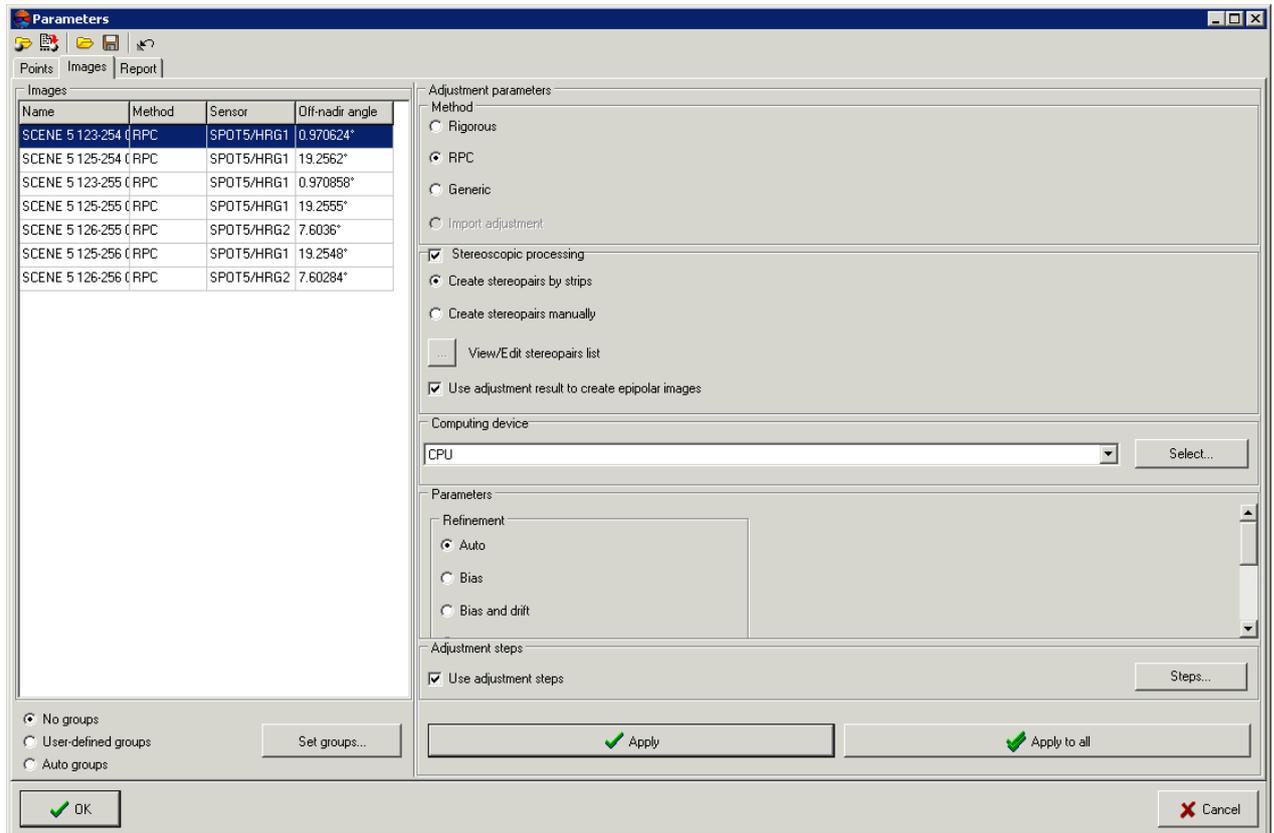
Fig. 26. Parameters of images adjustment using RPC coefficients

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;

- **Affine** – affine 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).

Fig. 27. Parameters a priory covariances

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

• **Bias (pixels)** – RMS of absolute terms of input refinement (in pixels) a priory;

• **Drift (p.p.m.)** – RMS of linear coefficients of input refinement a priory; it is dimension-less units and their value is setup in millionth parts (p.p.m. parts per million).

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 8.6).

> ⚠ 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.
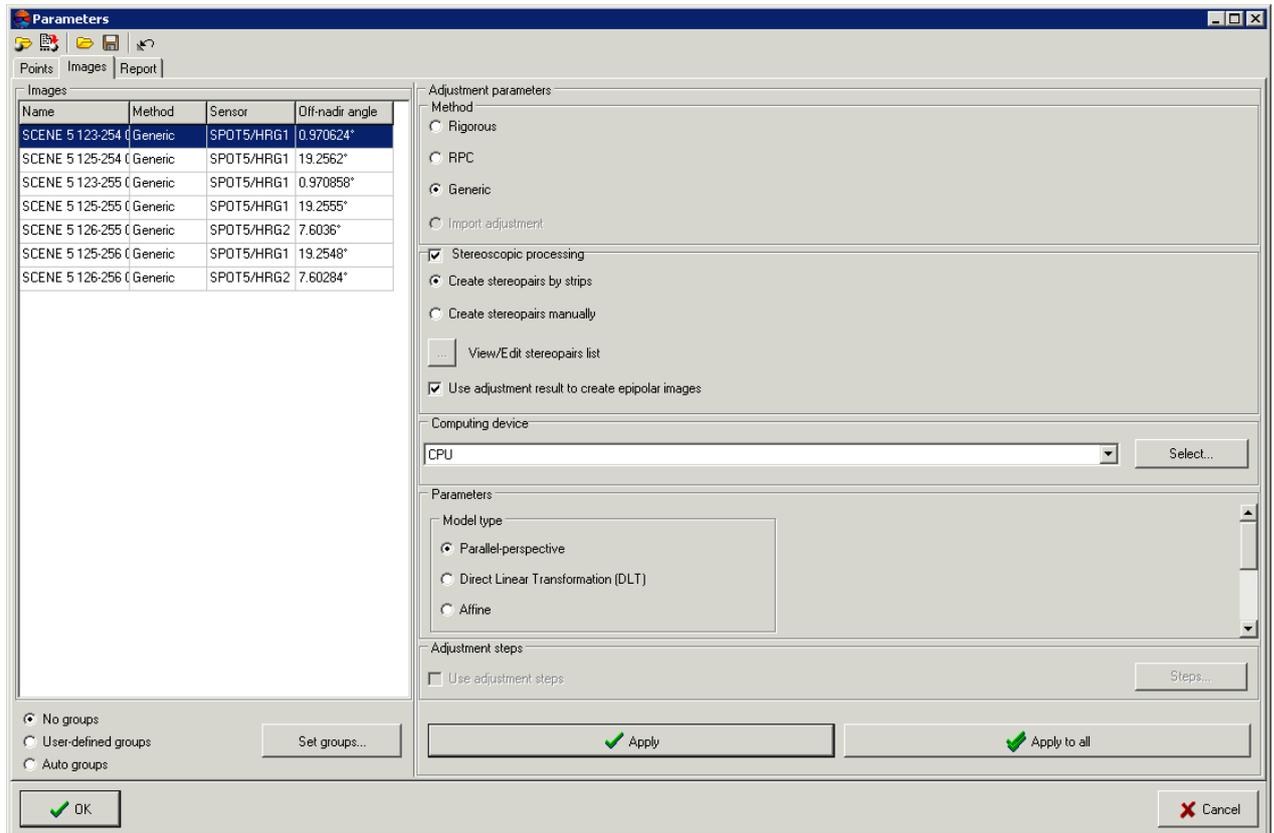
Fig. 28. Parameters of generic method of images adjustment

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.

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.
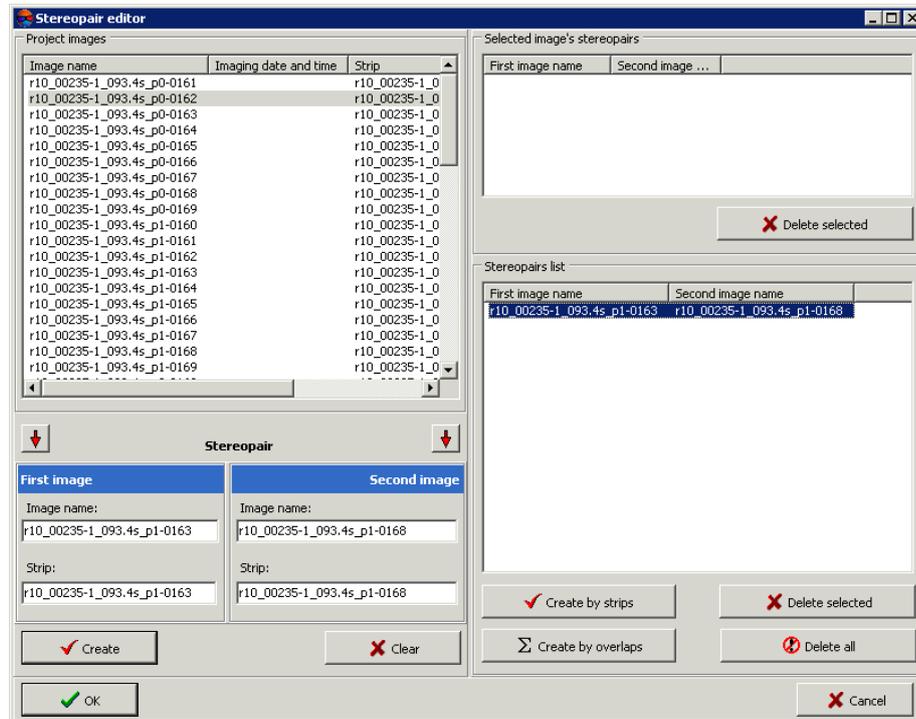
Fig. 29. The "Stereopair editor" window

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;

- **Selected image's stereopairs** – 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 form stereopairs manually from block images perform the following actions:

1. Click the 🖼 **Parameters** button. The **Parameters** window opens.

2. Click the **Images** tab and set the **Stereoscopic processing** checkbox on.

3. Select the **Create stereopairs manually** option and click the **View/edit stereopairs list** button. The **Stereopair editor** window is opened.

4. [optional] For automatic stereopairs creation from adjacent images of each strip and to add them to the **Stereopairs list** table click the **Create by strips** button.

5. [optional] To form stereopairs by parameters of images overlap in a strip, perform the following actions:

    1. Click the**Create by overlaps** button. The **Find stereopairs by overlaps** window opens.
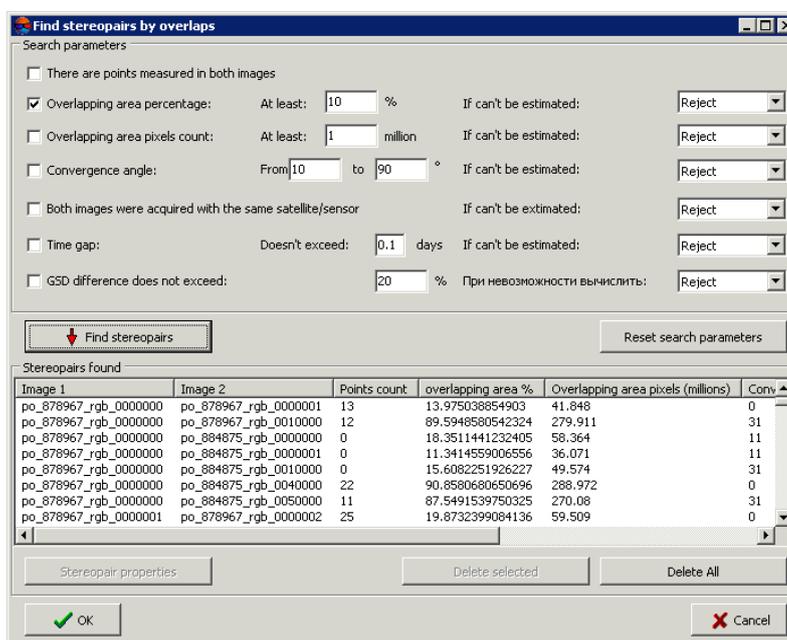
Fig. 30. Parameters of stereopairs search by overlaps

    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 **Doesn't exc...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.

> 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.

   3. [optional] To show stereopair's description, select the stereopair from the **Stereopairs found** table and click the **Stereopair properties** button. The **Save...** button allows to save stereopair's description in the text file.

   4. Click OK to return to the **Stereopair editor** window.

6. To form stereopairs manually perform the following actions:

   1. Select first image from the **Project images** table and click the left ⬇ button in the **Stereopair** section.

   2. Select second image from the **Project images** table and click the right ⬇ button in the **Stereopair** section.

   3. Click the **Create** button to confirm and add stereopair to the **Stereopairs list** table. Otherwise click the **Clear** button.

   4. Repeat actions from p. 6.1–6.3 to create more stereopairs.

7. [optional] To edit a list of created stereopairs use the ✖ **Delete selected** and the**Delete all** buttons, located under the **Selected image's stereopairs** and **Stereopairs list** tables.

8. Click OK 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.

    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.
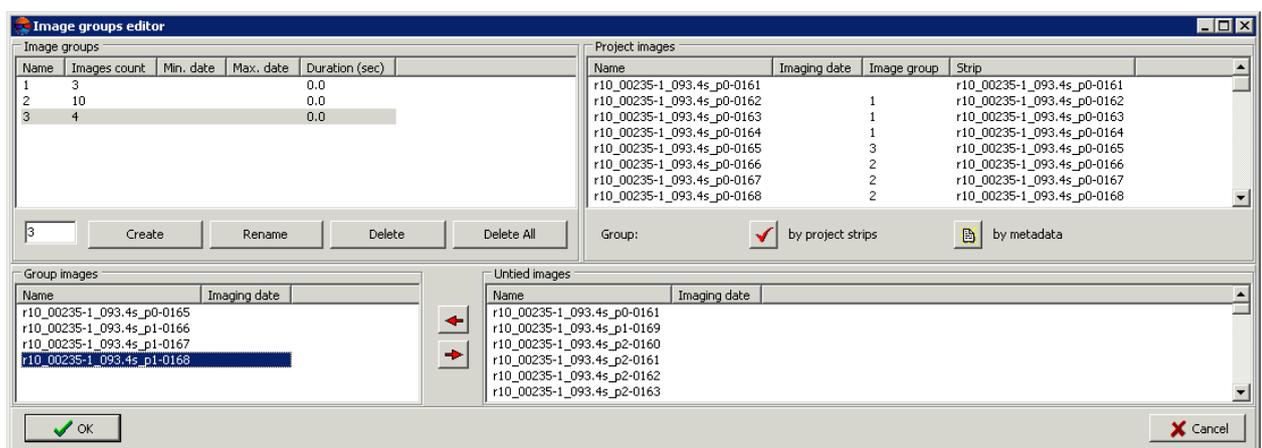
Fig. 31. The "Image groups editor" window

5. [optional] If it is possible to group images from each strip, click the ✔ **by project strips** button. In order to create images groups using metadata click the **by metadata** 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 under the **Image groups** table and click the **Create** 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 images in the **Untied images** table and click the ← button. Selected images will be shown in the **Group images** table. 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).

8. Create other images groups from the rest of images shown in the **Untied images** table.

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

10. 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.

11. Click the √α **Compute** button.

12. 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.
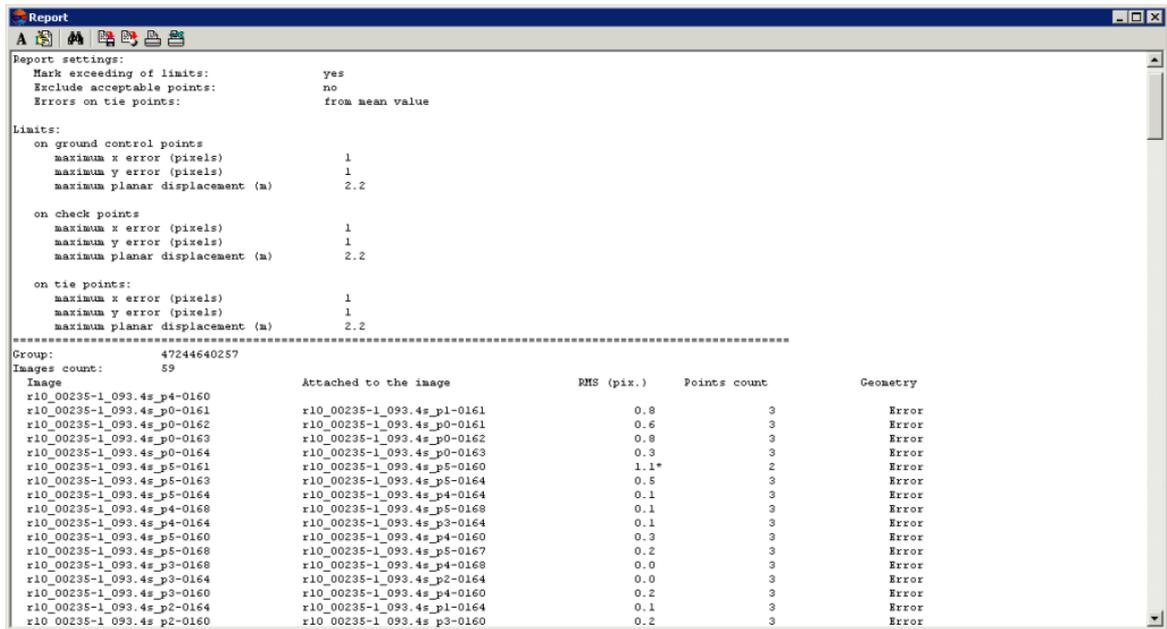
Fig. 32. Brief report on images groups
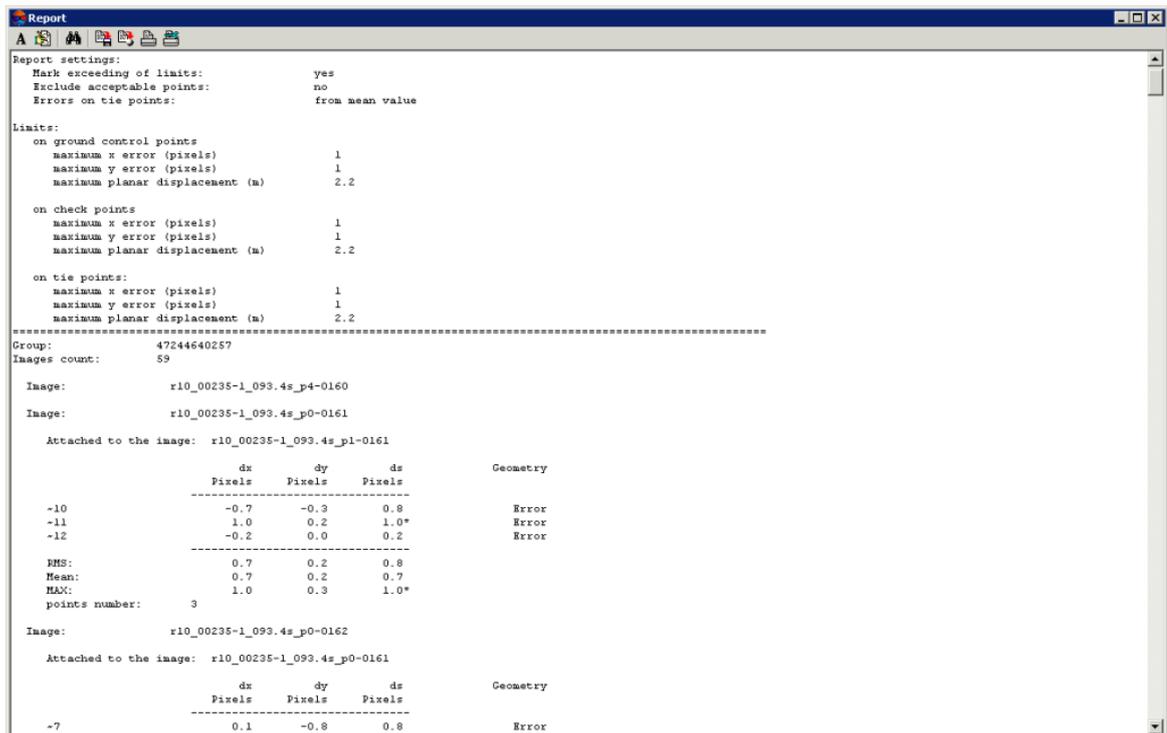
Fig. 33. Detailed report on images groups

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.
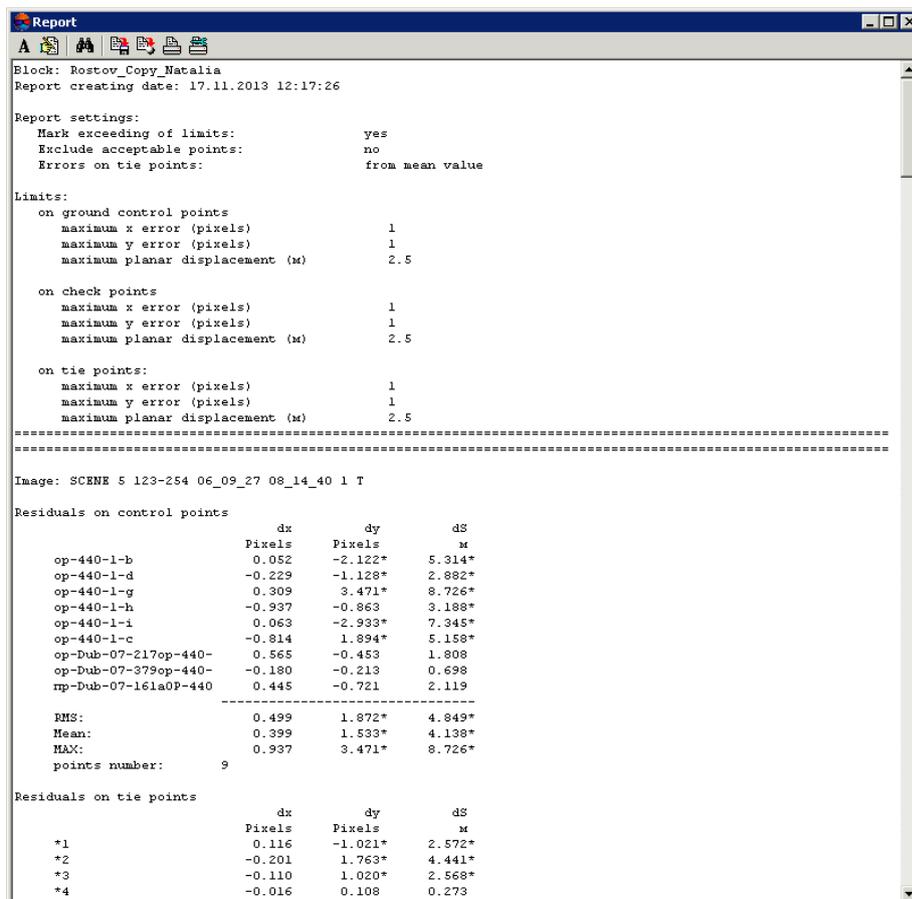
Fig. 34. Report on residuals obtained during images grouping

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.
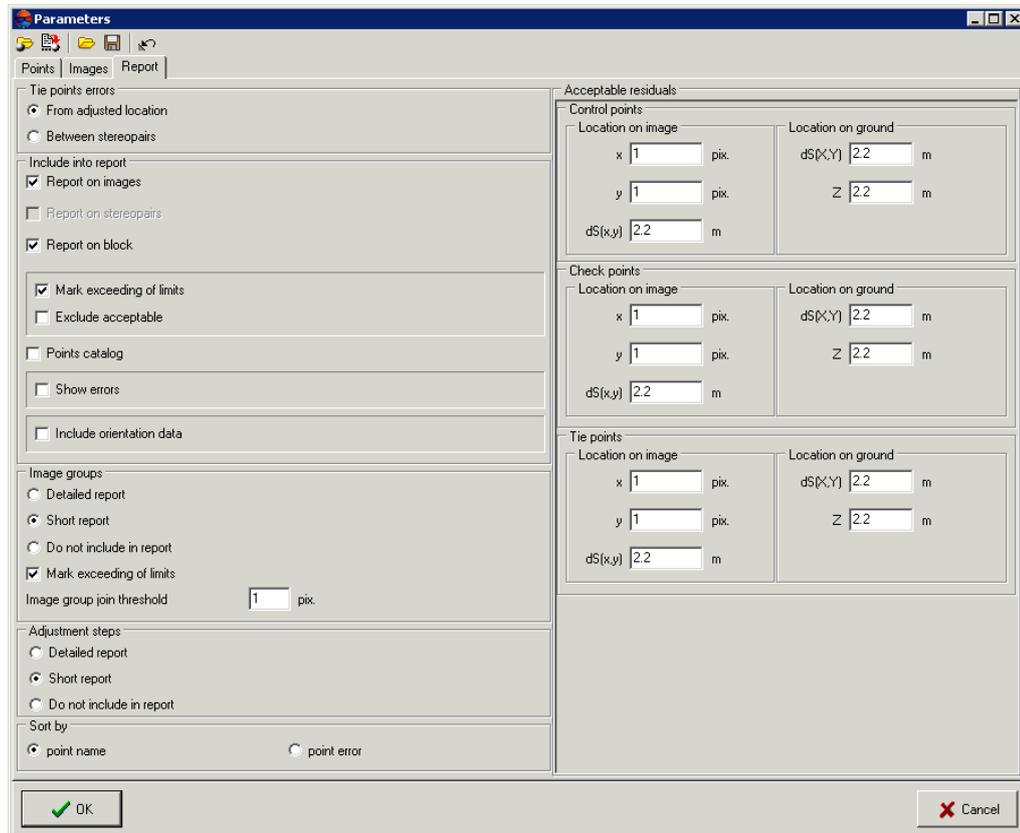
Fig. 35. Parameters on the "Report" tab

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

- the **Tie points errors** section is used to choose one of the following methods of re-siduals 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 **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;

  ○ **Report on stereopairs** – is used to include a list of stereopairs and values of ste-reoangles (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;

○ **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;

○ **Points catalogue** – is used to include to the report a list of adjusted coordinates of triangulation points (X, Y, Z);

○ **Show errors** – is used to add XY residuals values (Exy) and Z residuals values (Ez) to a list of adjusted coordinates;

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

• 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 **Acceptable residuals** section is used to input residuals threshold values: **control points**, **check points** and **tie points on image** and **on ground**;

• 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.

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.

8.5. 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.
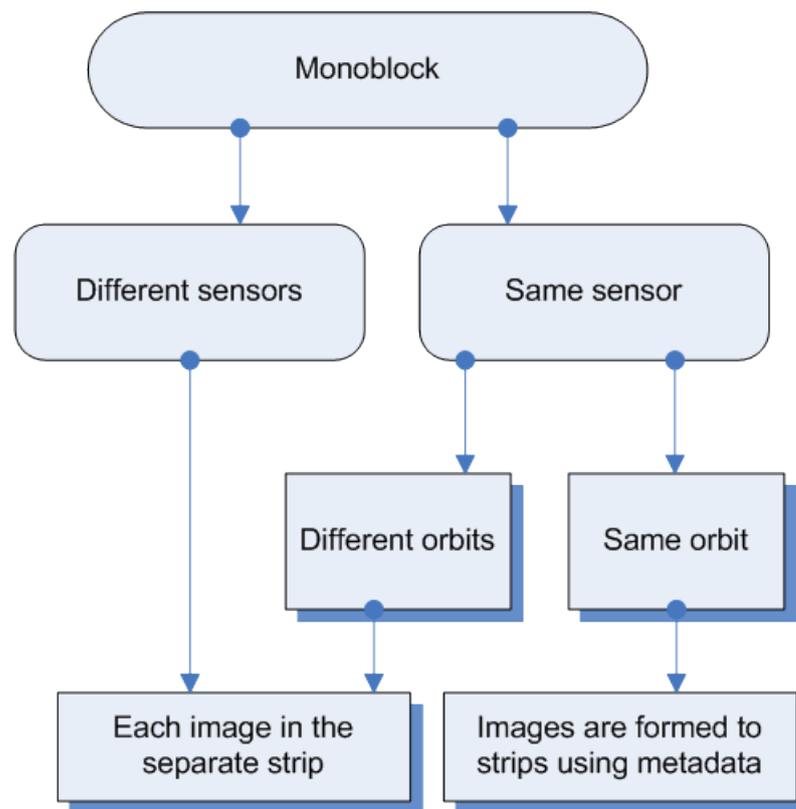
Fig. 36. Scheme of monoblock forming in the system

2. On step of triangulation points measurement there are the following recommendations concerning setup of parameters of automatic tie points measurements:
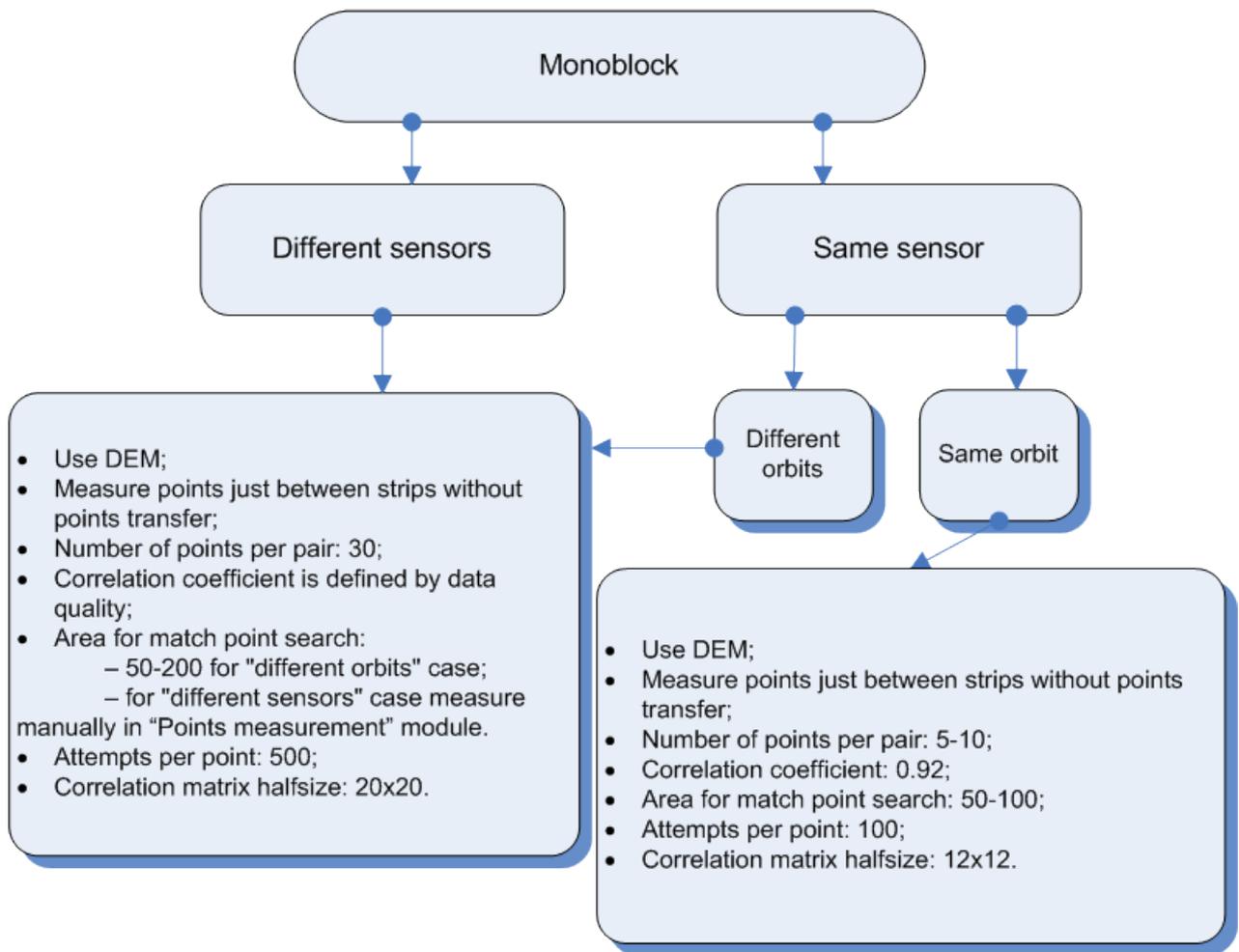
Fig. 37. Parameters of automatic correlation for monoblock

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 $\sqrt{\alpha}$ 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 $\sqrt{\alpha}$ 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.

8.6. 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).
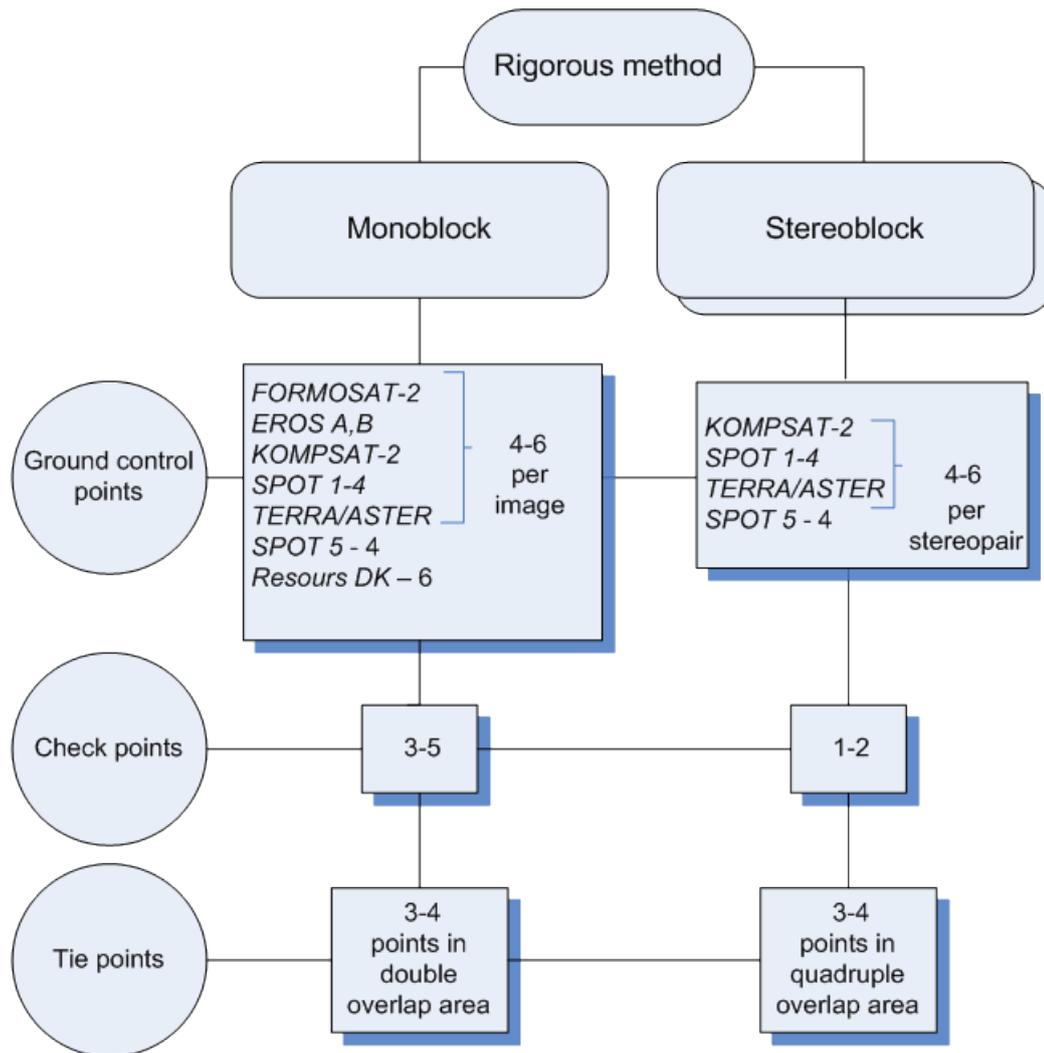
Fig. 38. Number of points recommended for adjustment of scanner block by rigorous method

☞ 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.
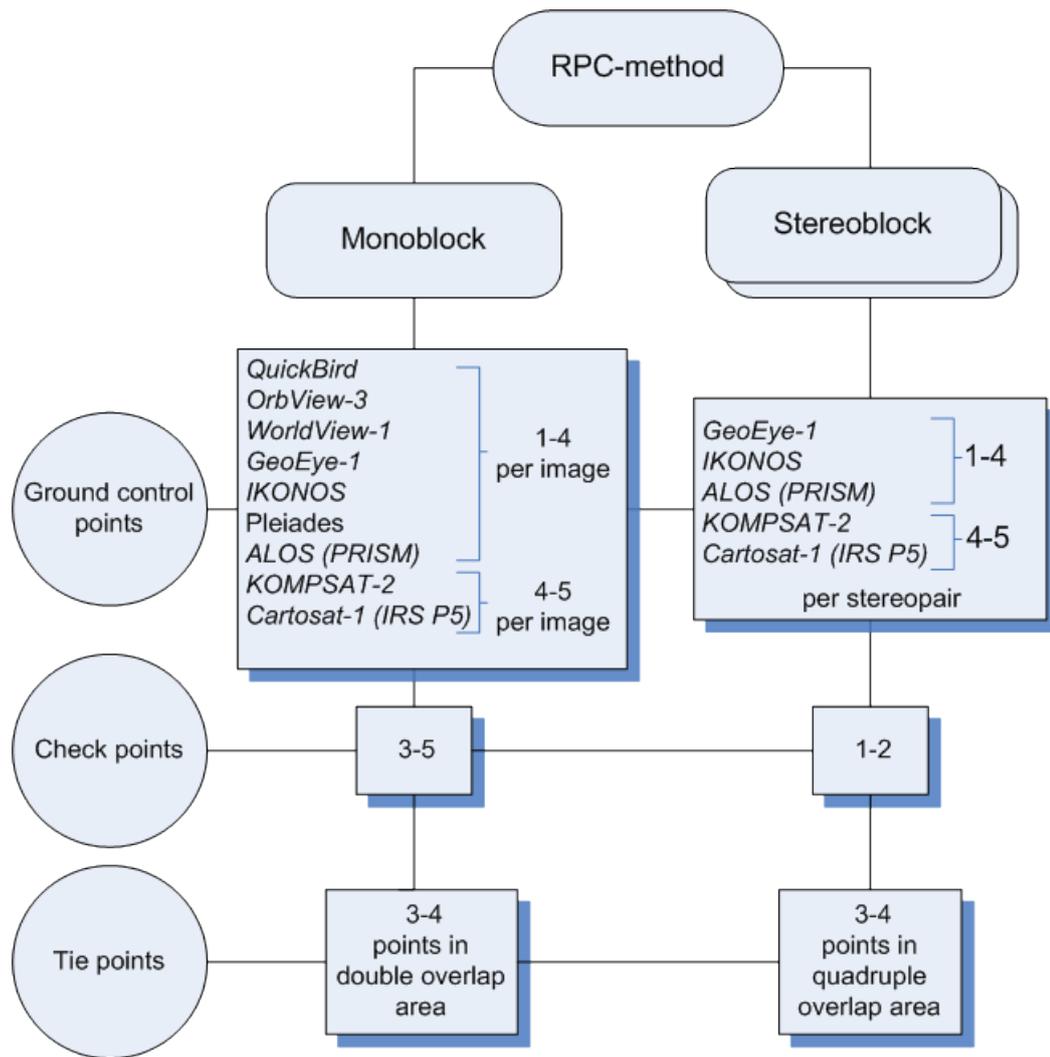
Fig. 39. Number of points recommended for adjustment of scanner block by RPC method

Number of GCP could be decreased due to tie points measured in quadruple overlap.
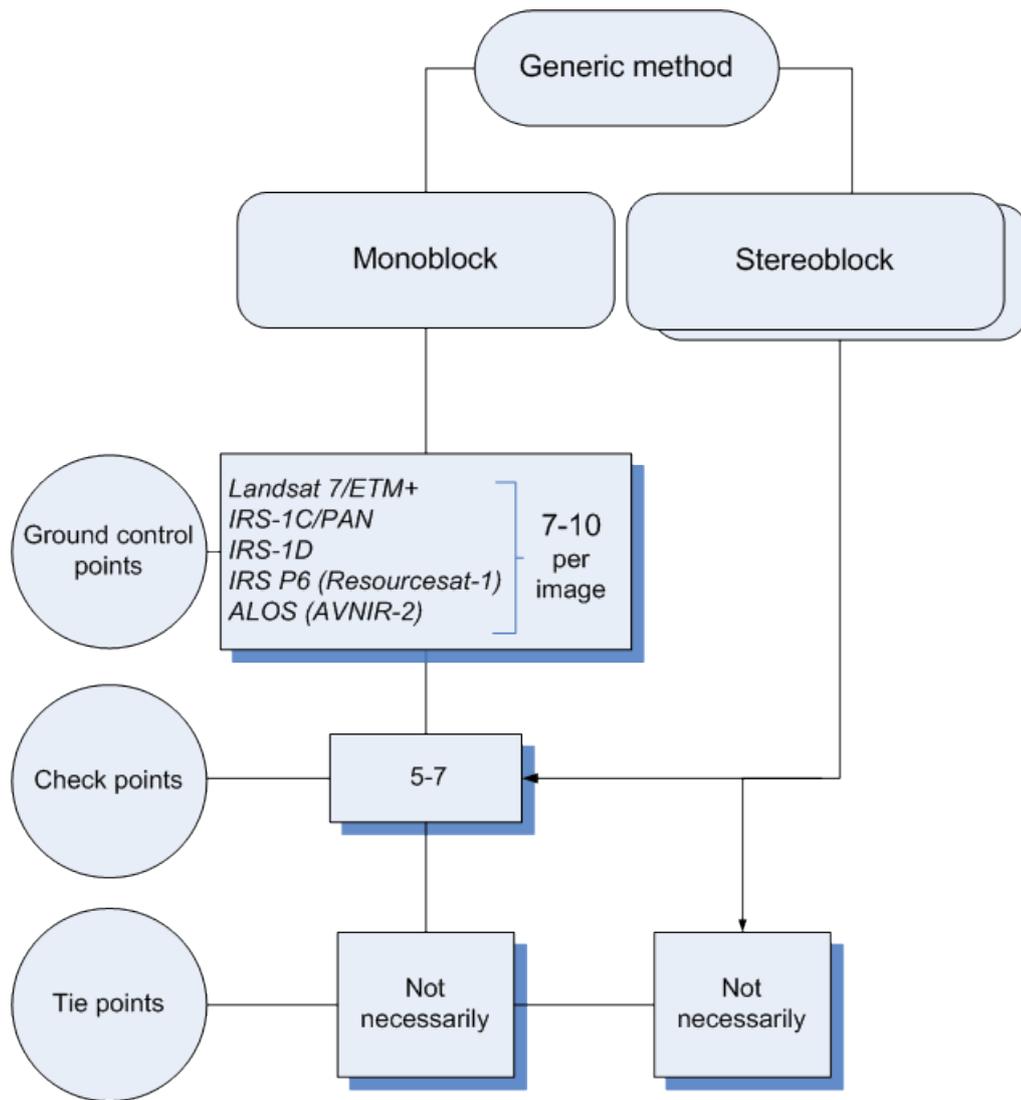
Fig. 40. Number of points recommended for adjustment of scanner block by generic method

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 √α**Compute** button. The calculation procedure is started and the window opens where the adjustment operation status is displayed.
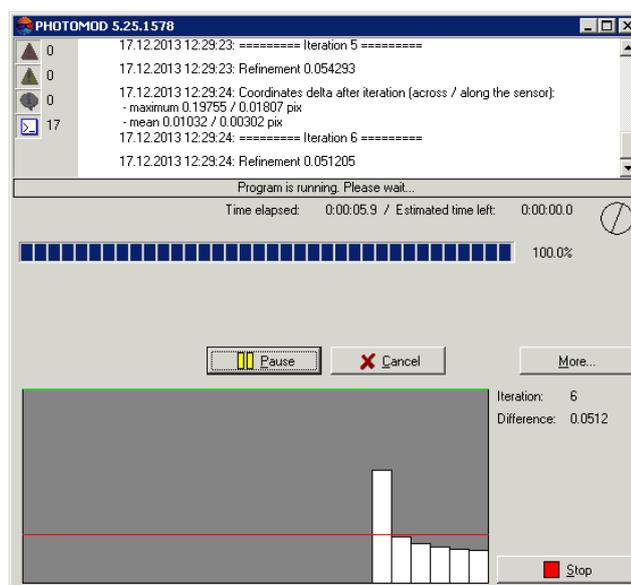
Fig. 41. Window of adjustment procedure status

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 13), 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 display adjustment report the 📄 button on the **Block adjustment** toolbar.


```
Report                                                                    _ □ ×
A  🖼  🔍 | 🖼 🖼 🖨 🖼
------------------------------------------------------------------------------

Estimation of block adjustment accuracy
Unacceptable residuals are marked with "*".
Points with acceptable residuals are not included in the report.

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

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


     mean absolute:      0.089         0.054         0.043         0.105
              RMS:       0.094         0.056         0.059         0.109
          maximum:       0.124         0.074         0.099         0.137
  number of points (differences):
                6 (         6             6             6             6)

Control projection centers residuals

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

           limit:       0.200         0.200         0.200         0.200


     mean absolute:      0.120         0.033         0.076         0.128
              RMS:       0.128         0.040         0.089         0.135
          maximum:       0.193         0.074         0.137         0.198
  number of points (differences):
               10 (        10            10            10            10)
------------------------------------------------------------------------------
```

Fig. 42. The window of adjustment report

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

• 🔄 – 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, dX*Y – GPS corrections on projection centers.

11. Adjustment accuracy control

It is recommended to perform control of block adjustment accuracy after the completion of the adjustment operation. The adjustment results are displayed in graphic form as a residuals vectors in the Stereopairs and Images modes of working windows, numeric values of residuals are included to adjustment report.

If the adjustment brought unsatisfactory results and there some blunders the system provides possibility to improve the results using editing of points position. To do this it is necessary "re-measure" points, on which the residuals vectors exceed defined threshold and are shown by red color.

In order to change point's type on image perform the following actions:

1. On a block scheme or in a list of points select a point, which residual exceeds specified threshold value.

2. In the **Points attributes** window click ⬛ the **Coordinates** button. The **Triangulation points** window opens. In this window coordinates of selected GCP and RMS are displayed. It is possible to change point's type in this window.

> Double-click of points name allows to open the **Points Measurement** window and change point's position.

In order to change point's position on image perform the following actions:

1. On a block scheme or in a list of points select a point, which residual exceeds specified threshold value.

2. In the **Points attributes** window click the ▦ **Measure** button. The **Points measurement** window opens.

   By default, a list with in only selected points is displayed in the **Triangulation points** window. Only these are also displayed on images.

   The following buttons on a toolbar of the **Triangulation points** window 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;

   - ▼ – points selected on the adjustment stage (for details see the *The "Points measurement" module* chapter in the "Aerial triangulation" User Manual).
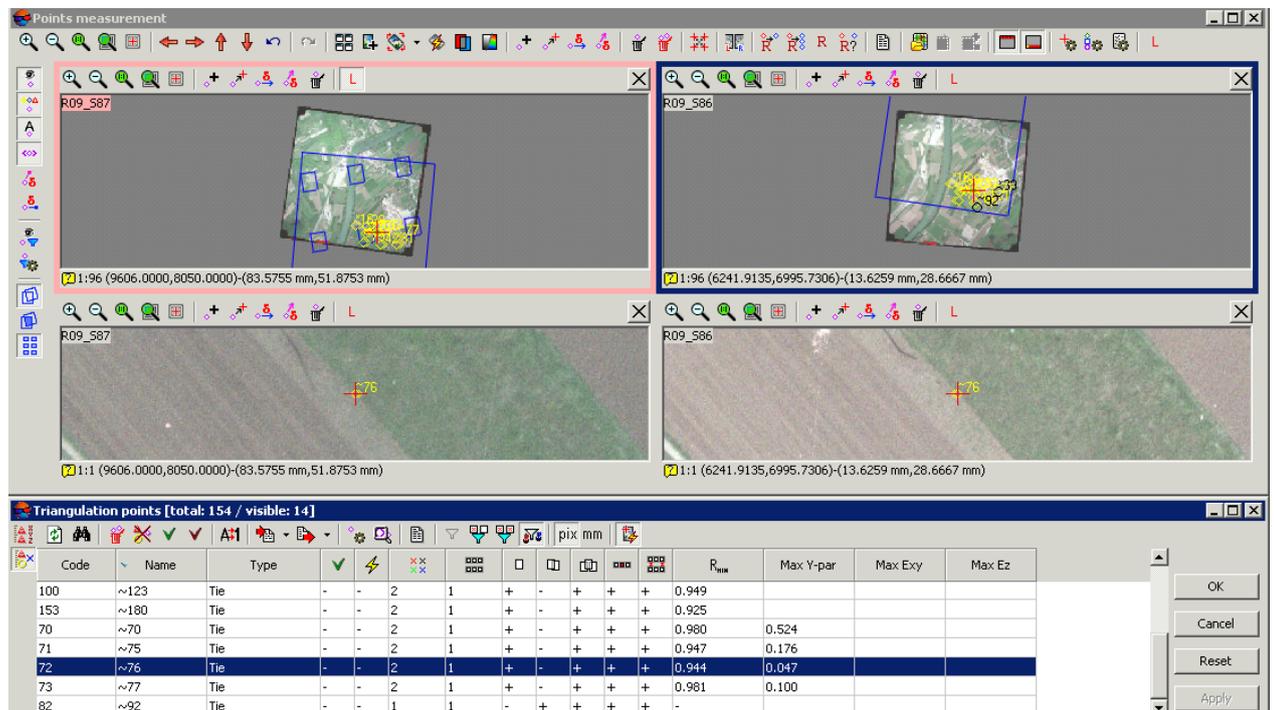
Fig. 43. Editing points shown in a list

3. Move a point manually or using correlator (see description of correlator work in the "Aerial triangulation" User Manual).

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

5.   Click the $\sqrt{\alpha}$ 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 co-ordinates of the points on adjacent images inside the strip during aerial triangulation or in the **Points measurement** window (see the "Aerial triangulation" User Manual).

12. Data export and import

12.1. 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.
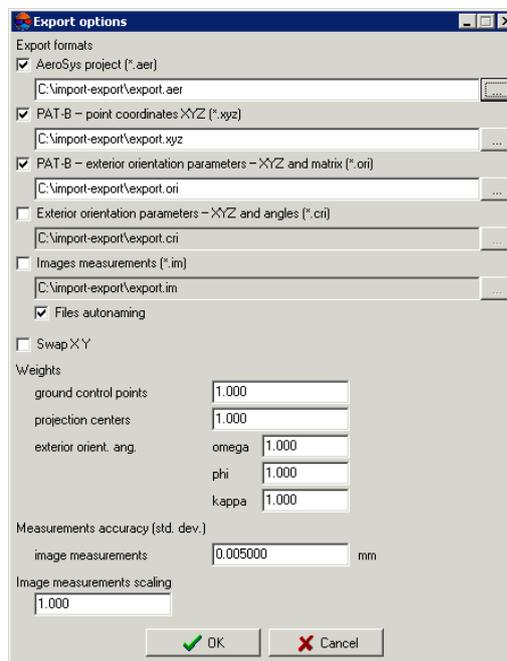
Fig. 44. Export parameters

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.

12.2. 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.
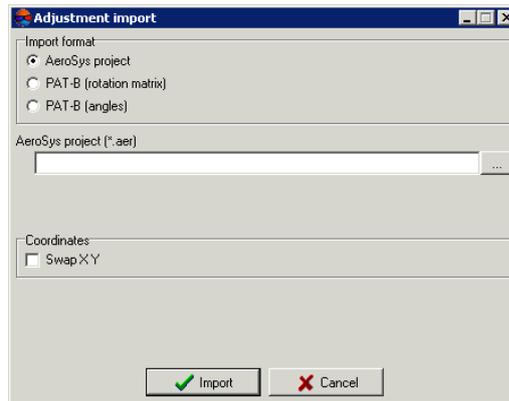
Fig. 45. Parameters of import from AeroSys project

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.
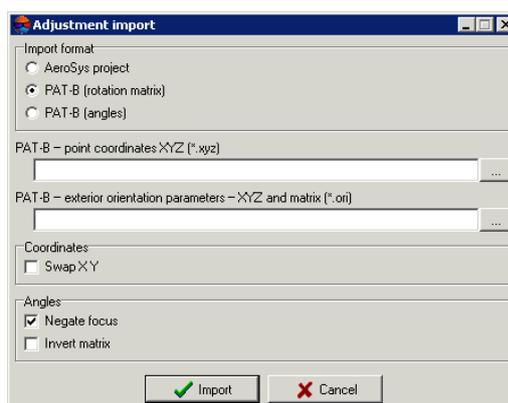
Fig. 46. Parameters of import from PAT-B format

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.
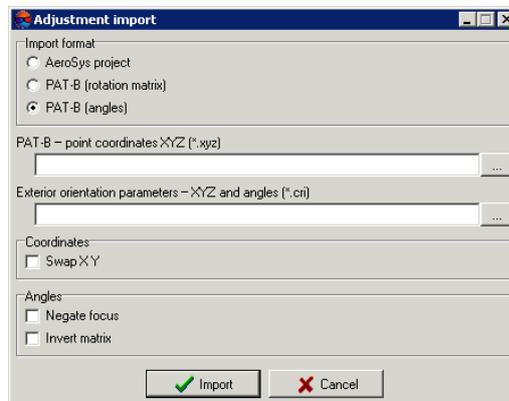
Fig. 47. Parameters of import from PAT-B format

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.

13. Stages of accuracy control

13.1. Adjustment control in free model

13.1.1. 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.

13.1.2. 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.

13.1.3. 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*.

13.1.4. 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.

13.1.5. 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.

13.1.6. 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.

13.1.7. 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 14.7).

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.

13.2. Adjustment control with geodetic reference

13.2.1. 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).

13.2.2. 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 √α 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).

13.2.3. 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.

13.2.4. 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.

14. Special aspects of airborne blocks adjustment in the system

14.1. 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.

14.2. 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.

14.3. 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.

14.4. 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).

14.5. 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).

14.6. 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.

14.7. 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.

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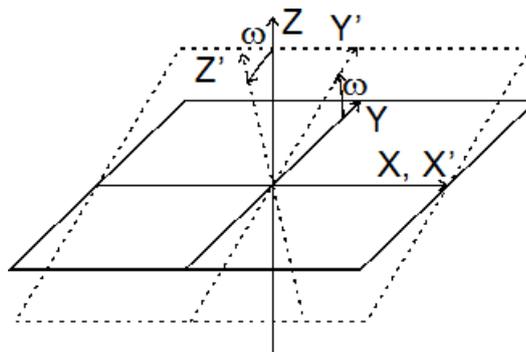
Fig. A.1. Rotation about X-axis at a positive value of "omega" angle

b)
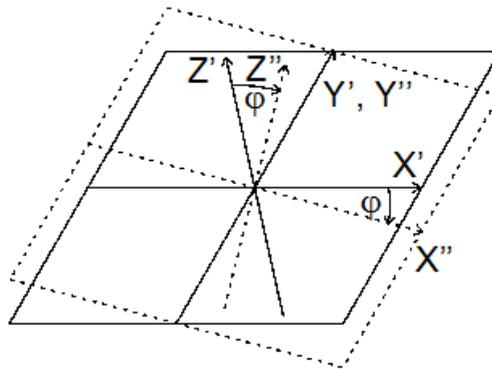
Fig. A.2. Rotation about Y-axis at a positive value of "phi" angle

c)
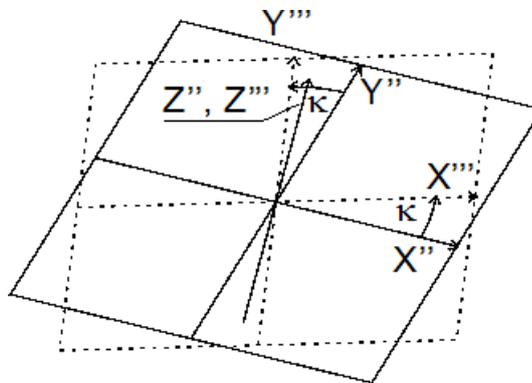
Fig. A.3. Rotation about Z-axis at a positive value of "kappa" angle

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

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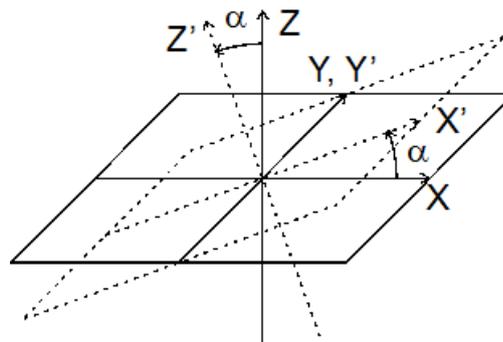
Fig. A.4. Rotation about Y-axis at a negative value of "alpha" angle

b)
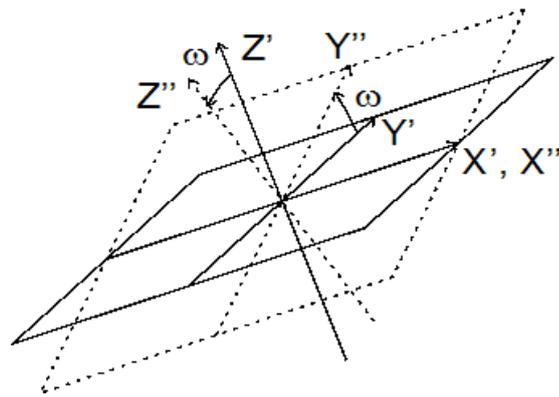
Fig. A.5. Rotation about X-axis at a positive value of "omega" angle

c)

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