PhoX

Version 2.5

October 2021

Photogrammetric Calculation System

Program Documentation

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Photogrammetric Calculation System

- Basic photogrammetric functions
- Full camera parameters
- Resection and DLT
- Forward intersection
- Monoplotting
- Relative orientation
- 3D coordinate transformation
- Interior orientation (fiducial marks)
- Import of multiple formats of photogrammetry
- Import of any coordinate files
- Simulation features
- Image measurement (manual/automatic)
- Contour measurement
- Image rectifications and image mosaics
- Stereo normal images and anaglyphs
- 3D stereo compilation
- 3D visualizations
- Extensive image processing functions
- Generation of geometric elements
- Generation of synthetic images
- Analysis functions
- Batch processing
- Project organization
- Integrated exercises

Imprint

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Content

1 General information

1.1 Application possibilities

PhoX is a program for processing and analysis of photogrammetric images and data. It is originally based on the program StereoMess that was used for teaching and research purposes at the Jade University. Compared to StereoMess, PhoX was improved and extended in many details.

1.2 Installation

1.2.1 System requirements

PhoX was tested with the operating systemsWindows XP, Windows 7, Windows 8 and Windows 10. The following minimal configuration for the computer is recommended:

- min. 4 GB RAM
- min. 2 GB free hard disk space
- fast graphics card
- Ethernet network adapter

The user interface of PhoX is optimized for a resolution of min. 1024 x 768 pixels. For the desktop, small or normal font sizes should be set.

1.2.2 Installation process

In principle, the executable file PhoX.exe can be copied to any arbitrary directory and run from there. For the program directory, write permission must be enabled because PhoX creates new files during the execution.

When the installation file PhoxInstaller.exe is run, all necessary files are copied into a user-selectable directory. Write access rights must be existing for the selected directory.

After installation the following files should be located in the program folder:

PhoX.exe	executable program PhoX
PhoX.plf	license file
PhoXmanual.cc.pdf	user's guide
PhoxQuickHelp.cc.rtf	quick help information in editable RTF format
PhoxAssistant.cc.txt	editable text file with instructions for various wizards for predefined workflows
PhoxExercises.cc.txt	editable text file containing descriptions of predefined training modules

cc. is a two-character country code, e.g. EN for English versions or DE for German versions.

1.2.3 Copy-protection dongle

In the copy-protected version for customers, PhoX is delivered with a USB protection dongle. With the first use of dongle, Windows (XP, 7, 8 10) detects a new device and automatically installs the corresponding drivers.

1.2.4 Program call

The call to PhoX.exe will start the program. Optionally, PhoX can be executed with the following parameters:

Phox.exe /D=*logfile projectfile*

/D=*logfile* generates a text file *logfile* during program execution with information on running program steps. If /D is used without a specified *logfile*, the file PhoX.log is created.

projectfile identifies a valid PhoX project file (.pxp), which is opened automatically when the program starts.

1.2.5 Versions

PhoX is available in different comprehensive program versions.

Customer version	dongle-protected full version with no time or feature limits
Academic version	full version with license file tied to the MAC address
Student version	limited functionality with central license file
Demo version	currently not available

The following table specifies which menu features in the individual variants are enabled.

Function	**Customer version**	**Academic version**	**Student version**
Project	X	X	X
Project:New project	X	X	X
Project: Preview project	X	X	X
Project:Open project	X	X	X
Project:Save project	X	X	X
Project:Save project as ...	X	X	X
Project:Close project	X	X	X
Project:Properties	X	X	X
Project:Import	X	X	X
Project:Import: Image coordinates	X	X	X
Project:Import:Orientations	X	X	X
Project:Import:Object elements	X	X	X
Project:Import:Add project	X	X	
Project:Import:Images from project	X	X	
Project:Import:Point covariances	X	X	
Project:Export	X	X	
Project:Export:Project	X	X	
Project:Export:Image coordinates	X	X	
Project:Export:Orientations	X	X	

Project:Export:Object elements	X	X	
Project:Export:VRML	X	X	
Project:Exit	X	X	X
Edit	X	X	X
Edit:Reset	X	X	X
Edit:Copy	X	X	X
Edit:Paste	X	X	X
Edit:Copy image graphic	X	X	
Edit:Options	X	X	X
Cameras	X	X	X
Cameras:Camera list	X	X	X
Cameras:Parameters	X	X	X
Cameras:Camera table	X	X	X
Cameras:Camera browser	X	X	
Cameras:Optics	X	X	X
Images	X	X	X
Images:Browser	X	X	X
Images: Lload image	X	X	X
Images:Save image	X	X	X
Images:Save all images	X	X	X
Images:Filter	X	X	
Images:Create images	X	X	X
Images:Image assignments	X	X	X
Images:Create thumb images	X	X	
Images:Properties	X	X	X
Images:Delete coordinates	X	X	X
Images:Image processing	X	X	X
Images:Synthetic images	X	X	
Images:Contrast slider	X	X	X
Measure	X	X	X
Measure:Image coordinates	X	X	X
Measure:Image contours	X		
Measure:Ground control points	X	X	X
Measure:Object coordinates	X	X	X
Measure:Model coordinates	X	X	X
Measure:Point cloud	X	X	
Measure:Spatial intersection	X	X	X
Measure:Interior orientation	X	X	X
Orientation	X	X	X
Orientation:Resection	X	X	X
Orientation:Relative orientation	X	X	X
Orientation:Absolute orientation	X	X	X
Orientation:Stereo models	X	X	X
Orientation:Rotation matrices	X	X	X
Orientation:Bundle adjustment	X		
Orientation:Bundle adjustment:Input data	X		
Orientation:Bundle adjustment:Adjustment	X		
Rectification	X	X	X
Rectification:Image Rectification	X	X	X
Rectification: Image to image	X	X	
Rectification:Image transformation	X	X	X
Rectification:Normal images	X	X	X
Rectification:Anaglyphs	X	X	X
Rectification:Distortion-free	X	X	
Objects	X	X	X
Objects:Object properties	X	X	X
Objects:Polygons	X	X	X
Objects:Transform	X	X	X
Objects:Calculations	X	X	X
Objects:Elements	X	X	X
Objects:Filter	X	X	
Objects:3D transformation	X	X	X
Objects:Meshing	X	X	X
Objects:Deformations	X	X	X
Objects:Image to object	X	X	
Objects: Color point cloud	X	X	
Objects:Create point images	X	X	

Graphics	X	X	X
Graphics:3D viewer	X	X	X
Graphics:VRML viewer	X	X	X
Graphics:Image footprints	X	X	X
Graphics:Distortion curves	X	X	X
Graphics:Analysis	X	X	X
Simulation	X	X	
Simulation:Image coordinates	X	X	
Simulation:Noise	X	X	
Simulation:Spatial intersection	X	X	
Simulation:Resection	X	X	
Simulation:6DOF	X	X	
Simulation:3D transformation	X	X	
Simulation: Ellipse eccentricity	X	X	
Simulation:Simulated images	X		
Simulation:Stereo images	X		
Processes	X	X	
Processes:Batch processing	X	X	
Windows	X	X	X
Windows:Mouse coordinates	X	X	X
Windows:Zoom window	X	X	X
Windows:Image properties	X	X	X
Windows:Point coordinates	X	X	X
Windows:Graphic window	X	X	X
Windows:Overview images	X	X	X
Windows:Diagram window	X	X	X
Windows:Button toolbar	X	X	X
Windows:Tile horizontal	X	X	X
Windows:Tile vertical	X	X	X
Windows:Cascade	X	X	X
Windows:Stack	X	X	X
Windows:Arrange	X	X	X
Windows:Reduce all	X	X	X
Windows:Enlarge all	X	X	X
Windows:Close all	X	X	X
Help	X	X	X
Help:Help window	X	X	X
Help:Instruction manual	X	X	X
Help:Homepage	X	X	X
Help:Error messages	X	X	X
Help:Assistant	X	X	X
Help:Exercises	X	X	X
Help:Registration	X	X	X
Help:About PhoX	X	X	X
Help:Updates	X	X	
Help:User info	X	X	

1.2.6 Student version

The student version of PhoX can be executed on all computers where the user has rights to read a central server directory where the basic version of PhoX is installed. PhoX cannot be executed directly from the server directory but must be installed always to a local directory, together with the license file PhoX.plf (using PhoXInstaller.exe). Often the access rights of students are restricted, e.g. for writing the Windows registry. For this case a local file will be created in the current program directory which contains basic registry and user information. This information is used to load recent program settings that are not included in the current project file (e.g. last user or recently loaded project files).

1.3 User Interface

1.3.1 Overview

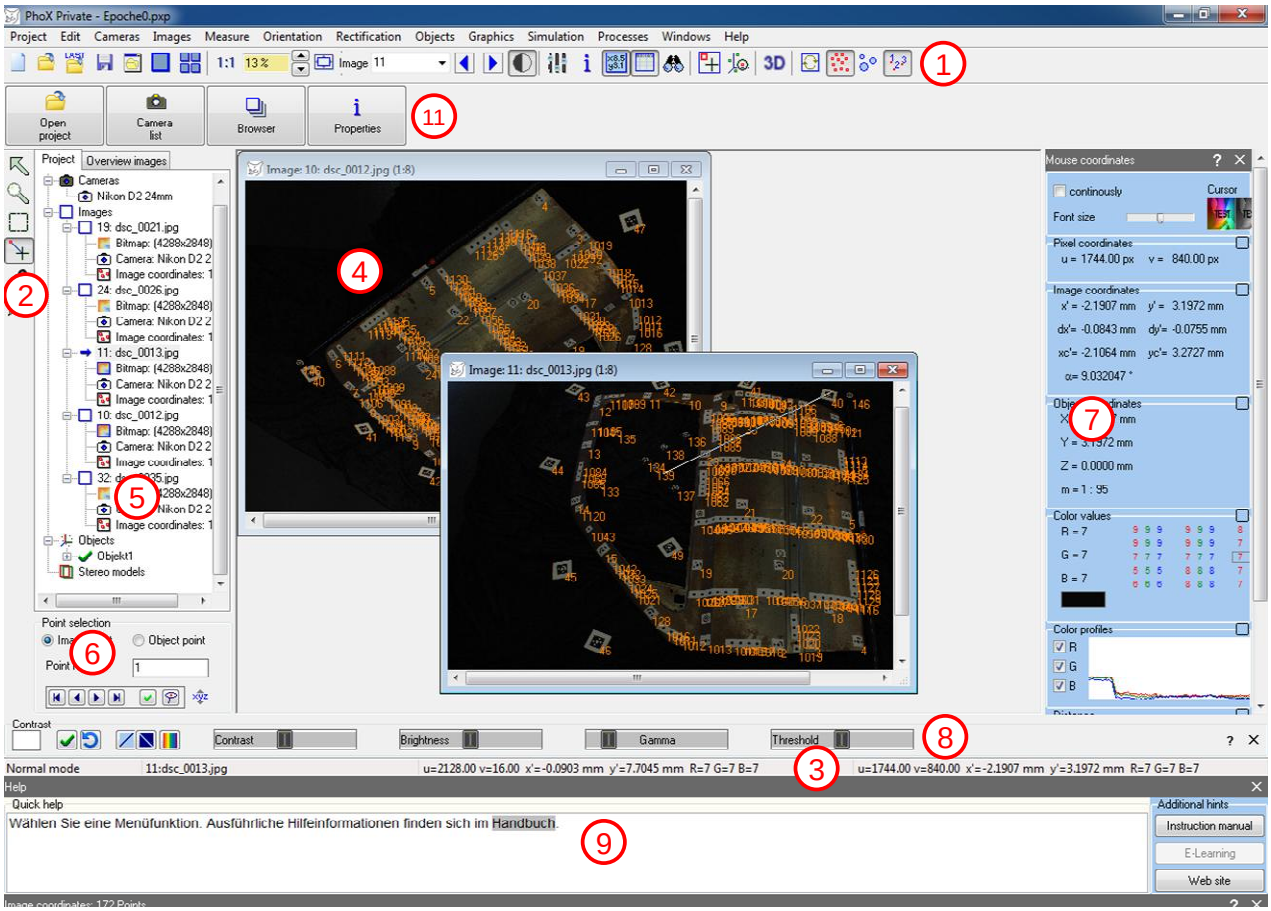


Fig. 1: User interface

The user interface is divided into the following areas:

(1) Menu and toolbar

The description of the menu functions follows in the next chapters. The buttons below the menu bar are used to quickly access of certain menu functions.

(2) Toolbar for image measurement

The tool bar contains buttons to enable or disable certain modes, including zoom, snap, pan, or similar functions.

(3) Status bar

In the lower status bar the current coordinates of the mouse position appear. The physical unit can be adjusted under **Edit/Options/General/Display**.

(4) Image window

The digital images appear in optional child windows, if there bitmaps are explicitly loaded.

(5) Project tree

a) Project

The project tree lists the elements of a project:

- Cameras
  - Name of the loaded camera
- Images
  - Name of the image file
    - Bitmap: Size of the image data
    - Camera: The camera name that is associated with this image
    - Image coordinates: The measured image points
    - Contours: Number of measured image contours
- Objects
  - Name of the 3D object
    - Points: Number of saved 3D points
    - Polygons: Number of stored polygons
    - Point cloud/DTM: Number of stored points of a point cloud or digital terrain model (DTM)
    - Triangles: Number of stored triangles of a meshing (TIN)
- Stereo models
  - Name of the stereo model
    - Image No.: left image
    - Image No.: right image

b) Overview images

Displays thumbnail representations of the images loaded into the image window. The corresponding image window is brought into foreground by mouse clicking. The corresponding image is panned and scrolled by moving the mouse while holding down the left mouse button.

(6) Point selection

Here image or object points can be selected and displayed in the open images. More information can be found in section 1.4.4 Point selection.

(7) Docking windows

Here, docked dialog frames are opened for the control of input and display of results depending on the selected function.

(8) Contrast controls

Here, four controllers appear optionally for the adjustment of brightness, contrast (gain and offset), Gamma value or a binary threshold for the current image window.

(9) Help information

Optionally brief contextual instructions and assistance can be displayed

(10)Point coordinates

Here, image or object points can optionally be displayed and edited.

(11)Custom toolbar

Optional display of a custom toolbar.

1.3.2 Toolbar, mouse and keyboard

Button toolbars

Fig. 2: Horizontal toolbar

The horizontal toolbar is associated with the following menu functions:

	Left mouse button	**Explanations**
	**Project/New project**	Creates a new (empty) project
	**Project/Open project**	Opens or imports an existing project file
	**Reload last project**	Reloads the last saved project
	**Project/Save project**	Saves the current project
	**Images/Load image**	Loads one or more images
		Loads the image selected in the project tree into the Image window
		Loads all images into the Image window
		Original resolution image display (zoom = 100%) Right mouse button: zoom all image windows
		View zoom in or out
		Fit image into window Right mouse button: adjust all image windows
Image		Activation of the entered image number
		Select the previous image window Right mouse button: first image of image list
		Select the next image window Right mouse button: last image of image list

	**Images/Contrast slider**	Show or hide the contrast sliders
	**Edit/Options**	General program settings
		Properties of the object selected in the project tree
	**Windows/Mouse coordinates**	Opens a docking window to display the current mouse and image coordinates and other image properties
	**Windows/Point coordinates**	Opens a table with current image or object points at the bottom of the screen
	**Windows/Overview images**	Opens a separate window with overview images (thumbnails) of loaded images
	**Windows/Image properties**	Opens a docking window to display various image properties
	**Measure/Image coordinates**	Measurement of image coordinates
	**Measure/Object coordinates**	Measurement of object points by forward intersection, spatial floating mark or monoplotting
	**Graphics/3D viewer**	Display the 3D viewer for the graphical representation of objects and cameras
		Update of graphical output in the image windows
	**Edit/Options/Graphics**	Show image coordinates in the image
	**Edit/Options/Graphics**	Show object coordinates in the image
	**Edit/Options/Graphics**	Show point numbers in the image

The vertical toolbar is associated with the following functions:

	Normal selection mode	Movement with pressed mouse button moves the visible image area
	Increases (left mouse button) or decreases (right mouse button) the image	When drawing a rectangle with the left mouse button the selected area is displayed enlarged
	Draws a rectangular area	Selection of an image area of that can be copied to the clipboard; use Shift for square area; Ctrl for centric square area. Image coordinate measurement: Selection of pixels
	Line cursor	Connects the last clicked point with the current mouse position (also with F4)

	Color picker tool	Sets the current drawing color with the color of the current pixel in an image window
	Color pen	Replaces pixels with the currently set color with pen width defined under **Edit/Options/General/Cursor**
	Drawing color	Selection of the current drawing color; in grey-level images (8 bit) the color appears in the corresponding grey value.

Keyboard commands

Button	**Image window**
F1	Call of the help function
F1 + Ctrl	Displays a PDF file belonging to the menu function, e.g. teaching slides
F2	Update of graphic output in the image window
F4	Switches line mode for cursors on or off
Ins	Opens a zoom window of the image at the current cursor position
Esc	Resets the current measurement mode back to normal selection or stops a current process of calculation (if implemented)
Del	Deletes the selected objects
Back	Centers the image window to the epipolar line
+	Enlarges the current image by one step
-	Reduces the current image by one step
F11	Saves a screenshot of the entire desktop to the clipboard
F11 + Shift	Saves this screenshot to the file ScreenShot_n.bmp
F12	Saves a screenshot of the current window to the clipboard
F12 + Shift	Saves this screenshot to the file ScreenShot_n.bmp
→	Shows the next image window
←	Shows the previous image window

Mouse control

Action	**Image window**
Left button	Trigger an action
Right button	Popup menu
Ctrl + wheel	Zoom the current image in or out

1.4 Program start

At program start PhoX opens a splash window with information about the current version and the user data.

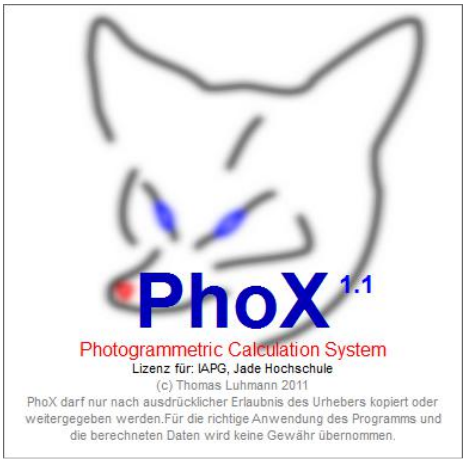


Fig. 3: Welcome window

The display can be enabled or disabled in **Edit/Options/General/Program**. The window can also be shown via the menu **Help/about Phox**.

1.4.1 Getting started

Working with PhoX is project-oriented, meaning that all images and data are managed under a project name. Saved projects can be reloaded later and contain all necessary information to proceed with the project.

Images are the most important source of data for photogrammetric projects. Images are managed in a PhoX project initially only as virtual objects that contain other data such as bitmaps, orientation data or image points. Each image is identified by a unique image number. The actual image files (bitmaps) are loaded and displayed for the visualization of image information or interactive measurement only on demand. Displayed images can be closed at any time and loaded again without losing data. Image files can be loaded and displayed via the Project tree or by functions in the **Images** menu.

Each image requires parameters of interior orientation. These are typically provided by a camera file that is assigned to the current image. Camera data can be created, loaded or saved under **Cameras/Camera list**.

Information about 3D objects (e.g. associated object coordinates points) is provided under Objects in the project tree. In an empty project, a new object must be created first before 3D data can be entered.

Global program settings are available under **Edit/Options**. Here, graphic displays can be configured, physical and decimal units can be set, as well as other parameters for program functions and much more. All settings are stored in the current project file.

A typical project flow for creating a new PhoX project (n images, 1 camera) can look like this:

1. Create a new project: **Project/New project** or double click on New project
2. Read image files: **Images/Load images** or **Images/Browser**
3. Define camera data: **Cameras/Camera list** or double click on Cameras

4. Assign camera data to images: **Cameras/Camera list**, **Images/Image assignments** or dragging the Camera on the Image name
5. Save project: **Project/Save project**

Depending on the application, typical evaluations of images may follow, e.g..

- Measurement of image coordinates: **Measure/Image coordinates**
- Image rectifications, orthophotos: **Rectification**
- Orientation of images: **Orientation**
- Measurement of object coordinates: **Measure/Object coordinates**
- Analysis of bundle adjustment results: **Graphics/Analysis**

Under **Help/Assistant** different typical workflows can be displayed, which are processed step by step by the user.

1.4.2 The project tree

The project tree shown on the left side of the screen represents an overview of the data in the project and allows the control of the project. The project tree has four main nodes:

- Cameras:

  List of all cameras loaded into the project; when no cameras are loaded, a double click on Cameras opens the camera window in accordance with **Cameras/Camera list**.

  By clicking and dragging (drag & drop) a camera onto an image object, this camera is associated with the image. This can also be done under **Cameras/Camera list** or **Images/Image assignments**.

  If a camera has been marked, the following popup menu is available:

  Camera list: opens the camera window **Cameras/Camera list**, where a new camera can be defined or an existing camera can be edited

  Delete: removes the selected camera from the list

  Duplicate: duplicates the selected cameras

  Parameters: opens the camera window **Cameras/Parameters**.

  Browser: opens the camera browser **Cameras/Browser**.

  The associated image icons have the following meanings:

  Camera loaded

- Images:

  List of all image objects loaded into the project; if no images are loaded yet, a double click on Images opens a file in accordance with the input dialog **Images/Load image**.

  If an image is loaded, it is initially invisible. More sub nodes to the image appear optionally under the image name in the tree:

  Bitmap: If a bitmap is loaded, the current image size in pixels is displayed here

  Double click: loads the image into the image window

  Drag & drop: dragging Bitmap into the main PhoX window also loads the image window

Camera: The camera name which is assigned to this image object

Double click: opens the camera window

Image coordinates: Number of measured or stored points in the image object

Double click: opens the image coordinate list

Contours: Number of measured or stored contours in the image object

Double click: opens the contour list

Image sequence: Number of images stored as an image sequence to the image object

Double click: opens the image properties of image sequences

In the popup menu, the following functions are available:

Select all images: selects all images in the project tree

Select numbers: opens an input mask for entering series of image numbers that will be selected; example: 11, 12, 15-19

Load image: opens the dialog to load new image files (**Images/Load image**)

Create images: opens the dialog for creating new images (**Images/Create images**)

If an image has been marked, the following popup features are enabled:

Open image file: input dialog to load an image file for the current image

Load and show: loads the bitmap and displays the image in the window

Load bitmap: loads the bitmap of the image file

Create bitmap: creates an empty bitmap of the appropriate camera image size

Remove bitmap: removes the bitmap of all selected images (no data loss)

Show image window: displays the bitmap of all selected images in the window

New: creates a new image object

Delete: removes the selected images with all data from the list (data and image are lost)

Duplicate: duplicates the selected images

Copy: copies the selected images into an internal clipboard

Paste: inserts all images from the clipboard as new images

Sort: sorts the images by ascending image number

Build stereo model: creates a new stereo model with the two selected image objects

Properties: opens the window with image properties

The associated image icons have the following meanings:

 Active image object

 Image object is disabled

 Bitmap file cannot be found under the stored file name

 Bitmap loaded

 Bitmap loaded and displayed in the image window

 Bitmap not loaded

- Objects:
  List of all 3D objects existing in the project; if no objects are available, a double click on Objects opens the properties of the object in accordance with **Objects/Object properties**.
  If an object has been marked, the following popup menu is available:
  Activate: selects the highlighted object as the active default object
  New: creates a new object
  Delete: removes all selected objects from the list (object data gets lost)
  Duplicate: duplicate the selected objects
  Copy: copies the selected objects to an internal clipboard
  Paste: inserts all objects from the clipboard as new objects

  Visible: change the visibility status of all selected objects
  Properties: opens the window with object properties.
  Sort: sorts the objects in ascending alphabetical order

  The associated image icons have the following meanings:
   Active object
   Invisible object

- Stereo models:
  List of all stereo models existing in the project; if there are no models, a double click on Stereo models opens the model properties in accordance with **Orientation/Stereo models**.
  Two sub-nodes for the left and right image of the stereo model appear in the tree under the model name. An image is associated with the model as left or right image by clicking and dragging (drag & drop) an image on a sub-node of the model. This can also be done under **Orientation/Stereo models**.
  If a model has been marked, the following popup menu is available:
  New: creates a new stereo model
  Delete: removes all selected models from the list
  Duplicate: duplicates the selected models
  Properties: opens the window with model properties

  Display images: displays both stereo image windows
  Exchange images: exchanges left and right image of the current model

  The associated image icons have the following meanings:
   Stereo model

1.4.3 The image window

For existing image objects, associated bitmaps can be loaded from file. Most common image formats are supported. Some measurement and image processing functions require a loaded bitmap and an open image window. Loading and displaying of a bitmap is possible through

- double-click the bitmap icon in the project tree or
- the popup menu of the project tree or
- the icon  in the top tool bar.

Different mouse and menu functions are available in the image window:

Action	**Mouse**	**Popup menu**	**Button**
Enlarge image	Ctrl + wheel forward	Enlarge	+
Reduce image	Ctrl + wheel backwards	Reduce	-
Original size (100%)		Original size	
Fit in window		Fit	
Open zoom window		Zoom window	Ins
Reset all		Reset	Esc
Copy frame		Copy	Ctrl C
Save image window		Save as	
Image properties		Properties	
Move image	Left button and moving		
Change the color channel		Color channel …	R, G, B, I, O
Center on epipolar line			Back
Detach cursor from epipolar line			Alt

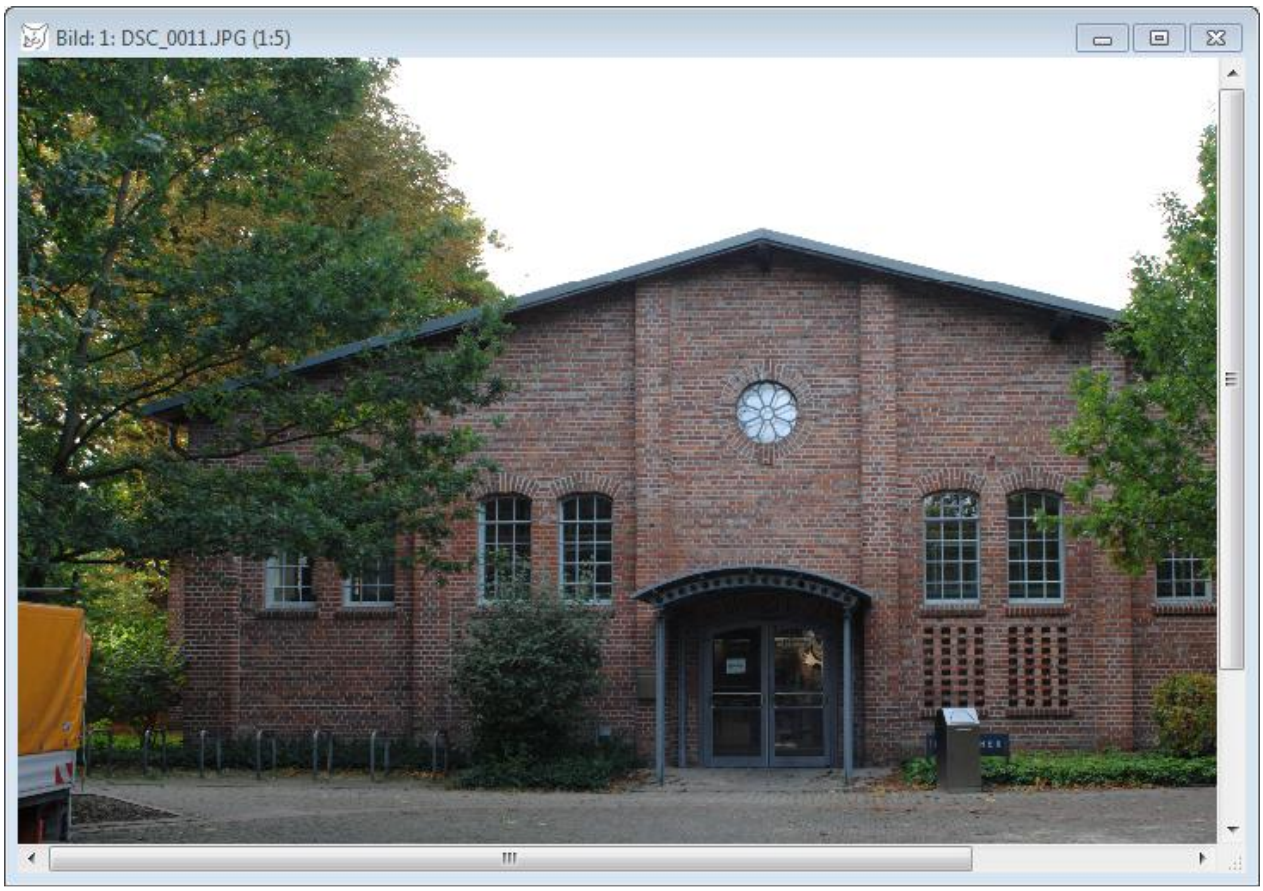


Fig. 4: Image window

The maximum possible zoom level depends on the image size and is calculated automatically. For precise point measurements, it is advisable to open the zoom window at the desired position via the right mouse button and measure in it.

The image window contains only a copy of the image file associated with the image object. Therefore, changes to the image window (e.g. brightness and contrast) will not affect the original image. For saving the image window, this can be done via the popup menu.

Popup menu functions:

Zoom window	Opens the zoom window
Reset	Resets the current measurement function
Image measurement	Opens the docking window for Measurement of image coordinates
Enlarge	Enlarges the image by one step
Reduce	Reduces the image by one step
Original size	Represents the image at 100% magnification
Fit	Fits the entire image into the image window
Copy	Copies the entire image to the Windows clipboard
Save as	Saves the displayed image, taking into account any changes in color
Properties	Opens the window with Image properties
Color channel	Represents the image in the color separations **Red**, **Green**, **Blue** or **Intensity** (grey values). The item **Original** loads the original image again. The function can also be

run by the keyboard commands R, G, B, I or O. For very large bitmaps, no color separations can be performed.

In the measuring mode *Draw rectangle* which can be activated with the tool button , the following popup menu is available:

Reset	Resets the current selection
Copy	Copies the selected section of the image to the Windows clipboard
Copy color values	Copies the color values of the selected image area as ASCII values to the clipboard; consecutive for grey value images, in the order R, G, B for color images.

A point is measured each by clicking with the mouse on the desired point. With F5 the closest existing point is selected and clicked. Using the key Ins or via the popup menu (right click) a small window is opened in which the enlarged environment of the point is shown. In this zoom window the point can be set more precisely. The magnification of the zoom window can be adjusted under **Edit/Options/General/Cursor**. The zoom window is closed by clicking in the image window and acceptance of measured coordinates or with Esc without taking the measurement.

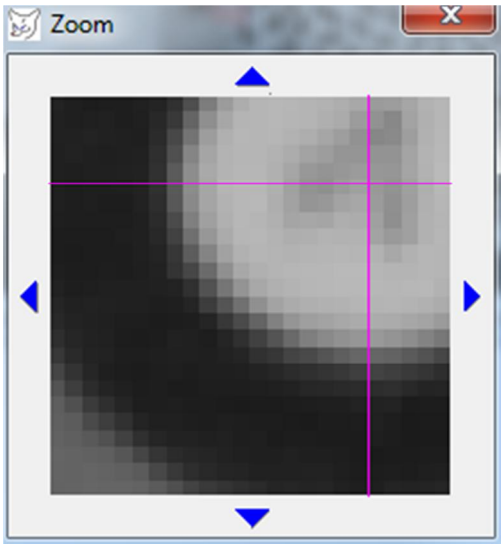


Fig. 5: Zoom window for exact point measurement

In the zoom window, the color channel of the represented image area can be changed using keyboard input (R=Red, G=Green, B=Blue, I=Intensity, O=Original color). Here, the original image is not changed. With the help of the buttons K and H contrast and brightness can be changed (Shift key for increasing, without Shift key for reduction of contrast/brightness). With the buttons + and – or the mouse wheel, the zoom factor can be changed until allowable limits are reached.

By clicking on the blue arrow symbols or pressing the arrow keys, the zoomed section can be moved to the right, left, top or bottom.

Keyboard commands:

F1	Call of the help information
Ctrl F1	Optionally displays a PDF file with explanations of the current function
F4	Cursor line on/off (line mode)
F5	Sets cursor to the next available point
Ctrl F5	Sets cursor to the next point and performs a mouse click
F9	Redrawing the image graphic
+	Zoom in image
-	Image zoom out
Ins	The zoom window
←	Shows the previous image window
→	Shows the next image window
R	Show red channel
G	Show green channel
B	Show blue channel
O	Show original image (all channels)
I	Display intensity or grey value channel
H	Increases (with Shift) or decreases (without Shift) the brightness
K	Increases (with Shift) or decreases (without Shift) the contrast

1.4.4 Point selection

A point selection panel is located at the bottom left of the screen. Here image or object points are selected and displayed either by navigation through the list or by catching with the mouse in the image window. The selection of image points can only take place if there are stored image coordinates to the images. Accordingly, object points can only be selected if there is an object with object points.

The selection of a point is done through

- Input of a number and pressing the button 
- With the navigation buttons
- Catching up with the mouse, after the button  has been activated. Then the cursor in the image window will change to a lasso and the point nearest to a mouse click is selected.
- By entering individual image or object coordinates, when the point panel is expanded with the button  and the input will be confirmed with  .

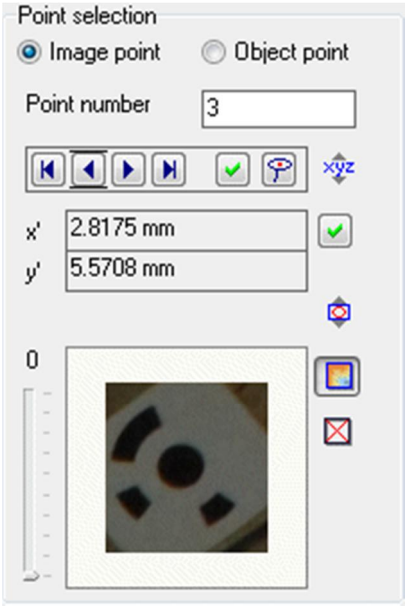


Fig. 6: Point selection

After selecting an item, all open image windows will be centered to the point. If the zoom window is opened, the corresponding zoomed images appear. The object points relate to the currently used object. The button activates a snap mode which searches for the nearest object point on a clicked image position.

The button expands the point selection window and displays the current image or object coordinates. Here individual coordinates can be entered which be shown in all image windows when is pressed.

The button again expands the point selection window and displays optional existing image thumbnails of the points. For every object point an unlimited number of thumbnail images can be stored. For every image point exactly one image can be saved. They can be useful when searching for control points, as an example. With the button the interactive mode for determining a point image is switched on or off. In active mode, a rectangular area to the desired point is raised in each open image window which is then saved as point image. With the button the displayed image of the point is deleted. The buttons and display the previous or next image of a point if several of them have been saved to a point.

In the popup menu of the image display, the following functions can be run:

Copy copies the indicated point image to the Windows clipboard

Import imports any image file as a point image for the current point

When the project is stored, the point pictures are stored as separate JPEG files in the subdirectory \PointImages\, and loaded automatically again when the project is reloaded (only for object points). The list of point images is stored in the text file *projectname*.pim. Point images can also be generated automatically with the menu function **Objects/Create point images**.

1.5 Program files and file formats

1.5.1 Directories

All files relating to the program can be found in the program directory where PhoX has been installed. In addition the following subdirectories are created either during installation or after the first program start:

\Cameras\	Contains the so-called camera library, i.e. here camera files can be stored in PhoX format and loaded easily through fast access in the Camera browser.

1.5.2 Project files (*.pxp)

All information belonging to a project is stored in a project file. The corresponding images are stored in their original format while the project file contains only the links to the image files. If image files are moved or deleted, the project can no longer be opened correctly.

With the function **Project/Save project as …** the storage type *Project archive* can be selected. It generates a complete copy of all project data including images into a new project directory without absolute path names. Project archives are suitable for the transfer of a project to another computer. The setting *Suppress path name* under **Edit/Options/General/Program** suppresses the output of directory names in the project file as well, for example, if the project file has to be copied to another host with a different directory structure.

PhoX automatically creates a backup file named $$Backup$ $_projectname.* in the current project directory.

Project files can be edited in any text editor, but this should be done only by experienced users. Most of the project parameters can be defined in the menu item **Edit/Options**.

1.5.3 Quickhelp file

The file PhoxQuickHelp.cc.rtf contains editable and formatted text in RTF format that appear at various functions at the bottom help window. The file contains predefined keywords that are not allowed to change. The texts stored to keywords can be overwritten by the user if necessary. Basic text formatting (font, bold/italic/underline, paragraph formatting, bullets) are displayed correctly. Hyperlinks are not recognized.

This help function is available only if the quick help file has been found. It is stored by default in the program directory (e.g. C:\Program files\PhoX). Help files are stored in PDF format.

1.5.4 Teaching materials

Through the Help window or the keyboard command Ctrl F1 a separate PDF file can appear that is associated with the current menu function, if it previously has been defined in the file PhoXteaching.txt. The structure of the file PhoXteaching.txt consists per line of the name of the menu function as well as the PDF file to display, e.g.

```
Measure:Interior orientation:=C:\Program files\PhoX\interior.pdf
```

The menu function is indicated by the topmost menu entry (here: Measure) hierarchically to the current function (here: Interior orientation), separated by a colon. The PDF file must be specified with the full path of the file.

1.5.5 Image files

PhoX processes both RGB color images (24 Bit) as well as intensity value images (8 Bit) in most common file formats. Input images can be in principle arbitrarily large, but depending on the operating system there may be storage limits (usually for 1 GB). The maximum permissible image size for output images (e.g. for rectification) is currently limited to 20000 pixels per line or per column or 300 MB per image.

Image files are read by PhoX from their original location (e.g. USB memory) and remain there. The project file contains only the link to the image file that is used. If the image file is deleted or moved to another directory, the file can no longer be loaded correctly.

1.5.6 Layout file

PhoX saves optionally all important program settings (colors, units, etc.) in the file phox.ini, which is stored in the program directory. This file is read automatically at the next program start independently of a project file. The file is only created if the user confirms with button Save under **Edit/Options**.

1.5.7 Measurement data

For the measured data within PhoX separate text files with the name of the project and individual file extensions are generated:

Image coordinates:	*projectname*.pho
Image contours:	*projectname*.con
Object coordinates:	*projectname*.xyz
Point clouds:	*projectname*.txt
Stereo models:	*projectname*.mod
Point image list:	*projectname*.pim

1.6 Data structures

1.6.1 Image objects

Image objects are the key data elements in PhoX. Any number of image objects can be managed. The most image information can be displayed or changed under **Images/Properties**. All necessary data is stored to an image object which is related to a single image. These include:

Image number:	Integer number that is unique for each image. The image number is used to identify the image in the image list.
Station number:	Integer number that indicates that an image belongs to a specific recording station. If a non-null number is assigned to multiple images, it means that these images are taken from the same position. Thus, for example, stereo cameras can be defined with their image pairs forming a common station.
Bitmap:	Digital image data which belongs to the image object.
File name:	Name of the file of that contains the bitmap (e.g. BMP, JPG).
Camera:	Associated camera from the list of loaded cameras. Even if no camera is assigned to, the image object, data of inner orientation is stored.
Interior orientation:	All data associated with the camera model, which are usually taken from an assigned camera.
Exterior orientation:	Data of exterior orientation
Image coordinates:	Measured image coordinates in the physical unit defined by the assigned camera unit (normally in millimeters). Each image point has a point number, x'-, y'-coordinates, standard deviations (sigma values) for each coordinate direction and an integer point code. Each point can be enabled or disabled individually.
Contours:	Measured image contours in the current unit (normally in millimeters). Each image contour consists of optional base points (nodes), as well as the automatically measured contour points between nodes.
Interest points:	Points detected with an interest operator are stored in a separate data structure without a point number as a series of 2D image coordinates.
Image sequence:	In addition to the original bitmap a series of equally large images can be saved to the image object. They can be created e.g. by the order of multiple image processing steps in a batch processing or loaded separately. Currently, the images of the sequence are not saved with the project.
Optics parameters:	Optional information about the recording (focal length, shutter speed, depth of field, etc.)

1.6.2 3D objects

3D objects are elements that include object coordinates, object polygons and other data. An arbitrary number of 3D objects can be managed. Most object information can be displayed or changed under **Objects/Object properties**. The essential information to a 3D object is:

Object name:	Name of the object. The object name is used to identify the object in the object list.
Object coordinates:	Any number of 3D object points. Each object point is marked with point number, X, Y, Z coordinates, standard deviations (sigma values) for each coordinate direction, an integer point code (attribute) and a timestamp (date and time). Each point can be enabled or disabled individually.
3D transformation:	7 parameters of a spatial coordinate transformation

Element parameters: Up to 8 parameters of a geometric element that is described by this object:
Default: no parameters
3D straight line: 2 parameters of a best-fit line in space
Plane: 4 parameters of a best-fit plane

Reference point: 3D coordinates of a reference point for the object, for example, projective center, point on a straight line or point in a plane

Polygons: Any number of polygons which are defined as topological line between stored object points.

Point cloud: Any number of unnumbered object coordinates (XYZ values only). Point clouds can be created in the program or imported.

Triangles: List from a triangulation (meshing, TIN) of triangular coordinates (**Objects/Meshing**).

Point images: Optionally one or more images can be saved for each object point to document the appearance of the object point, e.g. to search for control points with known appearance.

1.6.3 Cameras

Camera objects save all parameters belonging to a physical camera. Multiple cameras can be created and managed. Most camera information can be displayed or changed under **Cameras/Camera list**. Only one camera can be assigned to an image object. The camera data consists of three groups:

Description: General information about the camera (camera name, type, etc.)

Image coordinate system: Information to the camera model, the definition of the image coordinate system and the image sensor

Interior orientation: Details on the parameters of interior orientation (principal distance, principal point, distortion parameters)

1.6.4 Stereo models

Stereo model objects define stereo image pairs. An unlimited number of stereo models can be created and managed. The most model information can be displayed or changed under **Orientation/Stereo models**. Stereo models store the following data:

Image assignments: Image number of the left and right image

Model points: 3D points with xyz coordinates in the system of the stereo model

Orientations: Parameter of the exterior orientation in the model coordinate system (relative orientation)

1.7 Units and coordinates

1.7.1 Physical units

PhoX allows the use of different units for lengths, angle and other values. It has to be distinguished between the respective internal base unit (e.g. mm for lengths and coordinates) and the unit in which a value is displayed (e.g. meters).

Base units:

- Lengths, coordinates: Millimeter (mm)
- Surfaces: Square millimeter (mm²)
- Angle: Degree (°)
- Time: Hour (h)
- Frequency: Hertz (Hz)
- Resolution: Line pairs per millimeter (Lp/mm)
- Data: Byte (B)

Output units:

- Length, Coordinates: µm, mm, cm, dm, m, inch ("), foot (ft)
- Area: mm², cm², dm², m², inch², ft²
- Angle: Radians [rad], Degree [°], Grads [gon], Deg rees, min, sec (e.g. 22°12' 3 "), Millimeter/Meter [mm/m]
- Time: s, min, h, d, a
- Frequency: Hz, kHz, MHz, GHz
- Resolution: Lp/mm, dpi
- Data: B, KB, MB, GB, TB

Output units and number of decimal places are set under **Edit/Options/General/Display**.

Dialog boxes with input options for numeric values are highlighted, if values can be entered with a specific physical unit. For example, in the window below object coordinates can be entered. Currently they appear in the unit millimeters (mm). If the user, for example, enters the string "15.4 m", the input field detects the unit meter and will convert the value internally to 15400 mm. Input fields in white are restricted to enter values in the respective base unit only.

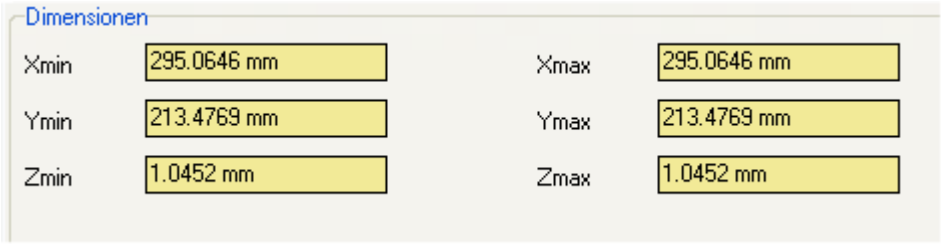


Fig. 7: Yellow fields with detection of the physical unit

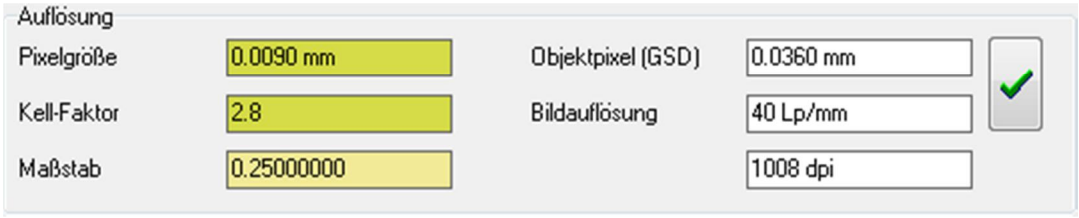


Fig. 7: Green fields with mouse control

Input fields, which are depicted in a shade of green, allow the change of the numerical value by vertical movement with pressed mouse button. The original value is changed with Shift in steps of 10%, with Ctrl key in steps of 1% and with Alt key in steps of 0.1%.

The colored marked fields provide the possibility to enter simple calculation formulas. The format of a formula is:

<Value1> <Operator> <Value2> =

Example: **15 * 0.22 =**

The operators *, /, +, - are supported. Parenthetical expressions or multiple operations are not allowed. The equal sign starts the conversion at the end of the input, so that immediately after entering the calculated result is represented in the input field, thus for the above example **3.30**.

With the input of a string in the format

<Value1> <Unit> =

Example: **15 cm =**

the value entered in the current unit will be converted. In the example above, the number **0.15** appears, if meter is set as the unit.

The program allows only the use of a period for the decimal point. The desired decimal point for import data from files can be set under **Edit/Options/General/Formats**.

1.7.2 Pixel and image coordinates

In PhoX the pixel coordinate system u,v is defined so that the upper left corner of the image has the pixel coordinates u = 0.0 and v = 0.0. A digital image is defined by m columns and n rows, i.e. the pixel coordinates of the lower right corner are u = m and n = v.

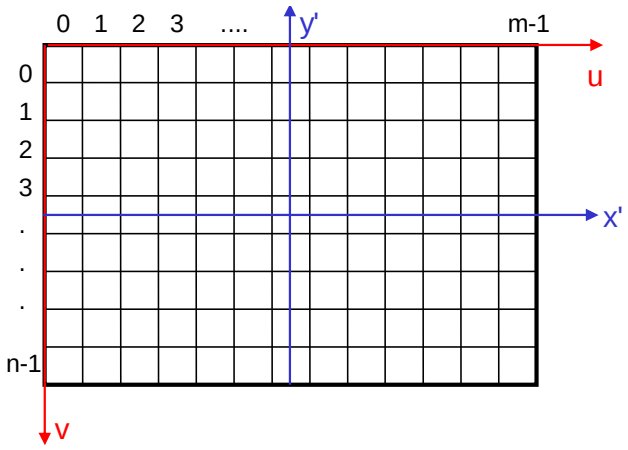


Fig. 8: Pixel coordinate system (red) and image coordinate system (blue)

A metric right-handed image coordinate system x',y' originating in the middle can be derived as follows from left-handed pixel coordinates:

$$x' = -\frac{s'_x}{2} + \Delta x_S \cdot u \qquad y' = \frac{s'_y}{2} - \Delta y_S \cdot v$$

$$s'_x = m \cdot \Delta x_S \qquad s'_y = n \cdot \Delta y_S$$

where s'_x and s'_y define the sensor size (in mm), m, n are the number of columns and rows, as well as Δx_s, Δy_s are the pixel size (in mm). The reverse transformation is carried out accordingly.

After reading a digital image, the right-handed x',y' image coordinate system is defined as described above in the middle of the image and has the unit pixels. Only after assigning a camera file with real pixel sizes a metric image coordinate system is created.

For visual reasons it is useful, if superimposed point symbols (for example, the center of a measuring mark) in the image window are drawn exactly in the center of the target (and not offset by half a pixel to top left). Therefore by default, all superimposed pixel coordinates are corrected by +0.5. A similar approach is used for the manual measurement of image points. Here as well, it is visually plausible, if the cursor is placed in the middle of a pattern and then measured pixel coordinates are shifted by -0.5. If necessary this half-pixel correction can be turned off under **Edit/Options/General/Cursor**.

1.8 Rights of use

The PhoX program may be used exclusively according to the license contract concluded during installation. Other uses are prohibited and will be prosecuted.

1.9 Exclusion of liability

PhoX was programmed and tested to the best of our knowledge and belief. Nevertheless, individual bugs cannot be excluded. The program supplier is grateful for every note on improving the program.

The program supplier assumes no liability for the correctness of the results returned. Any liability for consequences from the use of this program is excluded. The license agreement is valid with the program delivery and installation.

2 Menu Project

The **Project** menu provides functions for creating and managing project files as well as the import and export of data.

2.1 New project

Menu:	Project→ New project
Tool button:	
Project tree:	Double-click on node Project

The function **New project** creates an empty project. In the project tree nodes appear for Cameras, Images, Objects and Stereo models. According to the node type a popup menu is available by right mouse button that offers additional functions (e.g. load or remove images).

2.2 Project preview

Menu:	Project→ Project preview

The function **Project preview** opens an overview window with a file explorer to list PhoX project files and display previews. Each existing project file can be clicked in the right list panel. Depending on the preview mode selected information will be shown (number of images, description of the project) or preview images appear.
If the option *Scan subdirectories* is enabled, all subdirectories are searched for corresponding files starting from the currently selected directory. This may lead to longer processing times.

By double-clicking the selected file or with the button Load the project file will be loaded and the preview window is closed.

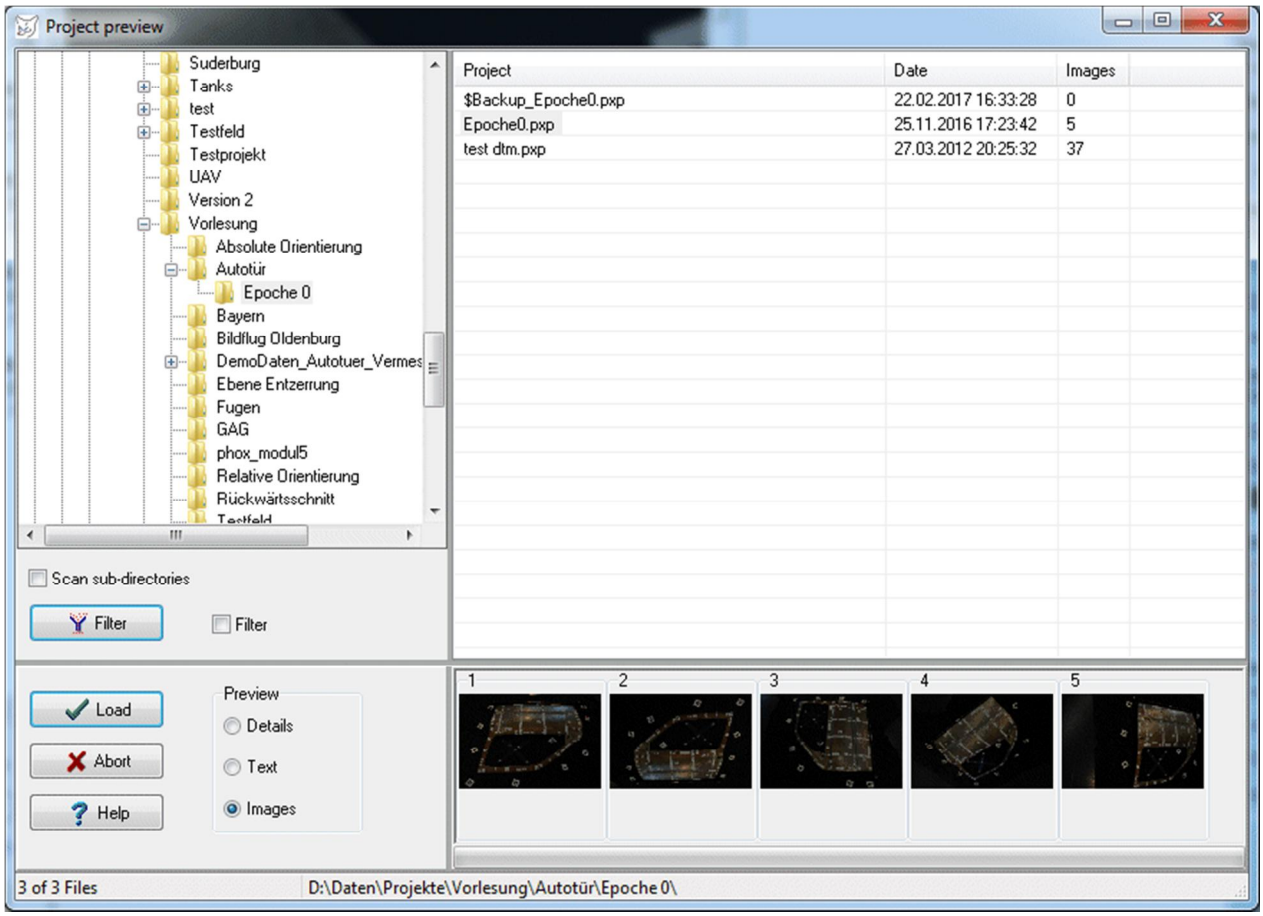


Fig. 9: Project preview

With the button Filter the following selection criteria can be set to search for project files:

Text	Search text must be included in the project files. Upper - and lowercase is ignored.
Created after	Input of the earliest file date. If the checkbox is marked, this date is taken into account when selecting the files.
Created before	Input of the latest file date. If the checkbox is marked, this date is taken into account when selecting the files.

The specified filter is used only when the option *Filter* is enabled. The number of filtered files found, as well as the total number of files in the current directory, are specified in the bottom status line.

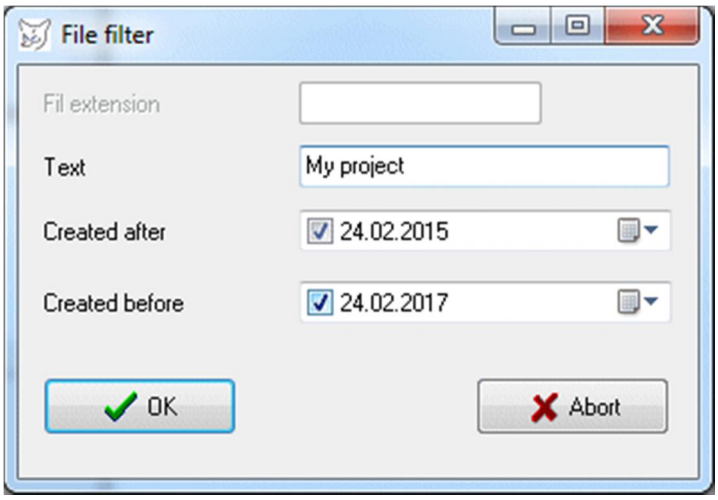


Fig. 10: File filter

2.3 Open project

Menu:	Project→ Open project
Button:	
Project tree:	Popup menu under node Project

In this menu item a PhoX project file (*.pxp) or another format (see below) is loaded which contains all the data and settings of a previously processed project.

If the project file contains references to image files that are not present in the selected directory, the user is asked whether he wants to search for the file. If the file is not found, the project file is loaded without the corresponding images.

A project file can also be opened by drag and drop from the file manager (Explorer) to the main window of PhoX or by double-clicking on the file name (extension .pxp).

The last eight open projects are displayed in the Project menu, and can be reloaded directly from there. With a click on the tool button  the most recently edited project is reloaded. Currently, the following project formats are supported:

- PhoX import (*.pxp)
  Hereby, PhoX files, where absolute path names for images and data files are stored, can be imported. The path names will be replaced by the paths that have been defined under **Edit/Options/General/Program**. In this way data can be imported from other directories.
- StereoMess files (*.prj)
  StereoMess files are supported by PhoX, but not all StereoMess functions are available in PhoX.

- AICON project files
  The import of AICON project files is based on the reading of *.ior, *.eor and other AICON formats, that usually appear in a common directory. AICON files may exist in 3D Studio format or in the old DPA format. Binary AICON project files are not imported.
- Ax.Ori output file
  The output file from Ax.Ori bundle adjustment (HTML format) is imported completely, but there is no link to the original image files.
- Bundle output file (TU Dresden)
  The output file of Bundle (HTML format) is imported completely, but there is no link to the original image files.
- iWitness output file
  The export file from iWitness (text format) contains information about the interior and exterior orientations as well as the used image files. All files must be located in the same directory. The import has been tested so far only for iWitness projects with only one camera. Object coordinates must be exported separately from iWitness and imported separately into PhoX. Measured image coordinates are not provided by iWitness.
- Agisoft Metashape output files
  For opening of an Agisoft Metashape project currently the default project export file in XML format can be imported:
  - Agisoft XML (*.xml)
  Within the file dialog the related file *project*.xml must be selected from where the parameters of interior orientation of one (1) camera and the exterior orientations of all images will be imported. Currently only 1 chunk can be loaded. The interior orientations will be transformed into a metric system automatically and assigned to the images. Their bitmaps will not loaded automatically but the related file names are stored with every image object (assumption: file format JPG).

2.4 Save project

Menu:	Project→ Save project	
Button:		Ctrl S

The current project data is stored in the already loaded project file without query.

2.5 Save project as …

Menu:	Project→ Save project as …

The current project data is stored in a file (*.pxp) after confirmation by the user. It is recommended to create a separate directory for each project, so that the user retains a better overview of the finished projects.

If the option *Project archive* is chosen under file type, the project file together with all additional files (images, coordinate files, camera files) is stored into a freely selectable (new) directory. A project archive can be used as a full data backup or as a computer-independent project file. No absolute program paths are used in an archive file, hence only the pure file name.

2.6 Close project

Menu:	Project → Close project
Project tree:	Popup menu under node Project

Closes the current project. If data have been changed before, the user is prompted to save the project. When modified bitmaps (e.g. following a change in contrast) exist, the user is prompted to store the image data.

2.7 Properties

Menu:	Project → Properties
Project tree:	Popup menu under node Project

The menu entry **Properties** shows a window with the most important characteristics of the current project.

File name:	Full file name of the current project file
Date	Date of the last modification of the current project file
Read only	Produces a read-only project file by using the file attribute "read only"
Operator	Input field where the name of the user for this project can be entered
Write protection	If checked, the saved project file cannot be deleted or replaced
Unblock project	If checked, the saved project can be loaded by any user
Cameras	Number of cameras managed in the project
Images	Number of images managed in the project
Objects	Number of 3D objects managed in the project
Stereo models	Number of stereo models managed in the project

Templates	Number of templates images (images for template matching)
Total RAM:	Size of total physical memory (RAM) in MB
Available:	Size of currently available memory in MB
PhoX:	Size of memory allocated by PhoX in MB
Bitmaps	Size of the main memory in megabytes currently occupied by loaded bitmaps
Windows:	Size of memory used by open image windows in MB
Description	Input field where any text about this project can be entered

The button [...] opens the Windows Explorer (file manager) for the current project directory.

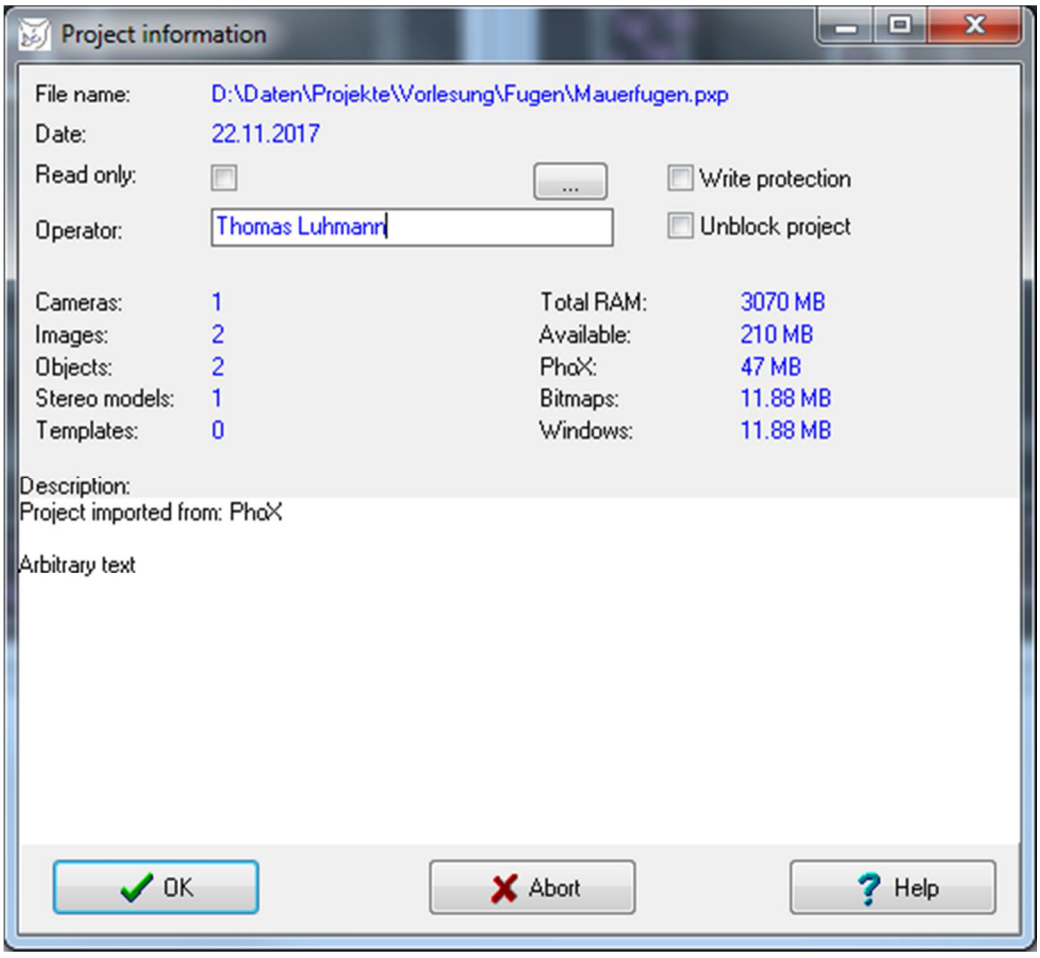


Fig. 11: Project properties

2.8 Import

Menu:	Project → Import
Precondition:	Project loaded

The menu entry **Import** is used for importing external data to the current project. Data of interior orientation or camera data can be imported through **Cameras/Camera list**.

2.8.1 Image coordinates

Menu:	Project → Import → Image coordinates
Precondition:	Min. 1 loaded image object

With the function **Image coordinates**, image coordinate files can be read in pre-defined or free formats. After the function call an image selection window appears, in which the images can be marked for which image coordinates shall be read from a file. Note: some formats for image coordinate files allow the storage of points for multiple images.

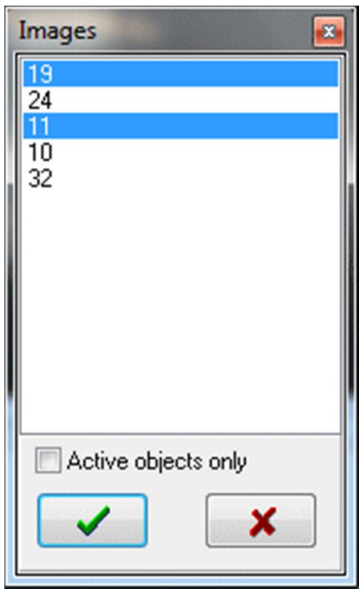


Fig. 12: Image selection

Currently the following input formats are supported:

Image coordinates (*.pho)	Image coordinates in the PhoX format: Image No. Point No. x' y' sx' sy' code
AICON (*.phc)	Image coordinates in AICON format: Image No. Point No. x' y' sx' sy' vx' vy' c1 c2 c3 When reading, the residuals from an adjustment vx',vy' are read as standard

	deviations of the point. The c2 parameter is stored as item code (1 = normal point; 0 = outlier).
AXIOS Ax.Ori (*.htm)	Image coordinates in AXIOS 3D format: Image No. Point No. x' y' vx' vy' sx' sy' rx ry tx ty When reading, the residuals from an adjustment vx',vy' are read as standard deviations of the point
Free format (*.txt)	Text files with the format that has been defined under **Edit/Options/General/Formats**.

2.8.2 Orientations

Menu:	Project → Import → Orientations
Precondition:	Min. 1 loaded image object

With the function **Orientations** exterior orientation data can be imported. After selection of the input format and file, PhoX reads the existing data of exterior orientation. If the imported file includes data of already existing images (associated with image number), the data is saved to these images. If the file contains data for non-existent images, these images are created.

Currently the following input formats are supported:

PhoX (*.pxp)	Exterior orientations in the PhoX project file format
AICON DPA-win/CDW (*.eor)	exterior orientations in the AICON DPAwin format (angles in gon): Image No., camera ID, X_0, Y_0, Z_0, ω, φ, κ, c1, c2, c3
AICON 3D Studio (*.eor)	Exterior orientations in the AICON 3D-Studio format (angles in rad): Image No., camera ID, X_0, Y_0, Z_0, ω, φ, κ, c1, c2, c3
Ax.Ori (*.html)	Exterior orientations in the Ax.Ori format (AXIOS 3D) as included in the output logfile from Ax.Ori
Bundle (*.html)	Exterior orientations in Bundle format (TU Dresden), as included in the output logfile from Bundle
LPS (*.dat)	Exported exterior orientations in LPS format: Image No., image name, camera ID, system ID, X_0, Y_0, Z_0, ω, φ, κ
iWitness (*.txt)	Exported exterior orientations in iWitness format. The translation parameters are stored under Xc, Yc, Zc, the rotations under Omega, Phi, Kappa. The image assignments are given via the name of the corresponding image file.
AgiSoft XML (*.xml)	Exported exterior orientations in XML format by AgiSoft Metashape
AgiSoft Export (*.txt)	Exported exterior orientations in format "omega phi kappa" by AgiSoft Metashape: Image file, X, Y, Z, ω, φ, κ, r11, r12, r13, r21, r22, r23, r31, r32, r33
Free format (*.*)	Import of any text file with exterior orientations. An additional dialog will be opened to read the input file.

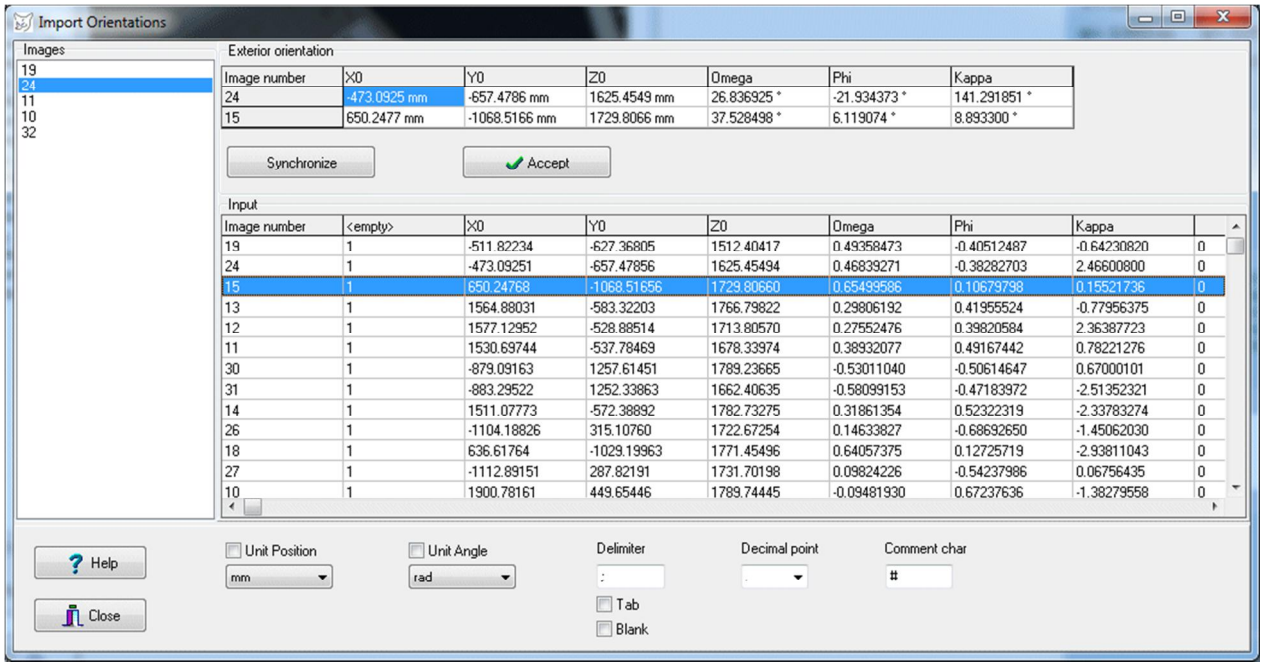


Fig. 13: Import window for exterior orientations in free-format input

Under Images the list of previously selected images will appear.

Under Input the imported text file appears. Each column gives the parameters of the associated exterior orientation. By clicking the title bar of each column, the associated parameter can be selected. Here input columns can be ignored (<empty>), when the input file contains values or texts that do not belong to the exterior orientation. Clicking a row in the input table, the decoded data will be displayed in the bottom line under Exterior orientation. The top line displays the orientation data already stored to the current image object.

When *Unit Position* is turned on, translations of exterior orientation are interpreted in the selected metric unit. The input parameters correspond to the possible settings under **Edit/Options/General/Formats**. If *Unit Angle* is selected, the rotation angles of the exterior orientation are interpreted in the selected angle unit. *Delimiter* specifies which characters are used to separate the individual strings of the input file. Under *Decimal point*, the decimal separator used in the input file (point or comma) is set. The characters entered under *Comment characters* are used to define comment lines or rows to be excluded from input.

The input dialog distinguishes two modes: if the option Synchronize is activated, all image numbers selected under Input will be sought and marked in red. With the button Accept all orientation data will be copied. However, if the button Synchronize is disabled, only one image object and one input object can be selected, which data then will be imported by Accept.

2.8.3 Object elements

Menu:	Project → Import → Object elements

3D objects can be imported with the function **Object elements**. Up to now, these are lists with 3D object coordinates. After selection of the input format and reading of the selected file, PhoX automatically creates a new 3D object, under which the data is stored. It is not necessary to have previously created images.

Currently the following input formats are supported:

PhoX (*.xyz)	Object coordinates in the PhoX format: Point No., X, Y, Z, sX, sY, sZ, code In addition, polygons, transformation parameters and other information are stored in the file.
AICON (*.obc)	Object coordinates in AICON format: Point No., X, Y, Z, sX, sY, sZ, c1, c2, c3, c4
STL (*.stl)	Object coordinates in STL format
Ax.Ori (*.html)	Object coordinates in Ax.Ori format (AXIOS 3D), as included in the output logfile from Ax.Ori
Bundle (*.html)	Object coordinates in Bundle format (TU Dresden), as included in the output logfile from Bundle
Points XYZ (*.*)	Object coordinates in format: X, Y, Z
Free format (*.*)	Object coordinates in the format that has been defined under **Edit/Options/General/Formats**

Before reading, an import window is opened where the text file is displayed and input parameters can be set, for example, the metric unit of stored coordinates. When *Unit* is turned on, the input data are interpreted in the selected physical unit. The input parameters are equal to parameters under **Edit/Options/General/Formats**.

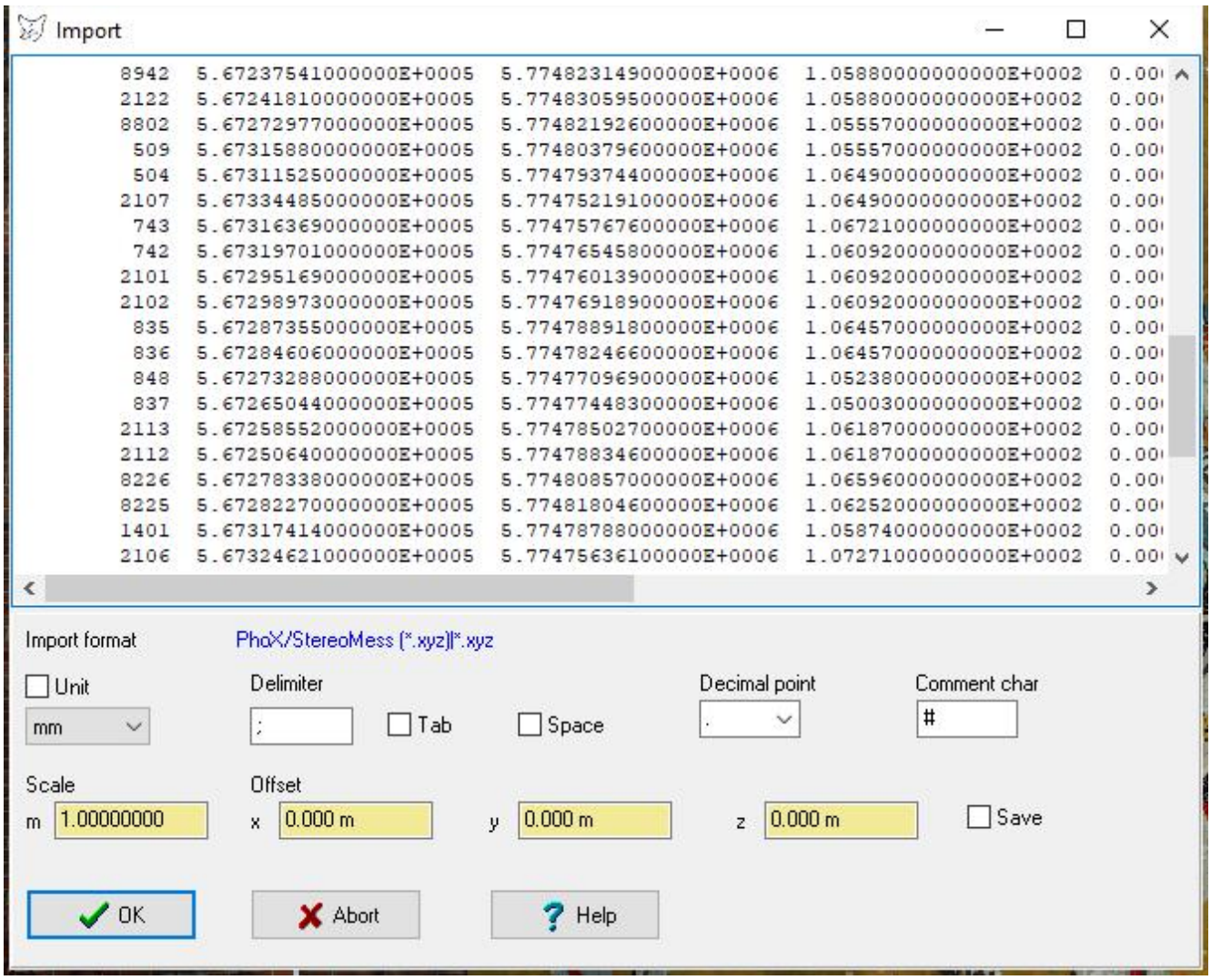


Fig. 14: Import window for object coordinates

The values defined under *Scale* and *Offset* are used to transform the coordinates. If *Save* is activated, these transformation parameters are stored with the current object when the project file is saved.

2.8.1 Point cloud

Menu-Aufruf:	Project → Import → Point cloud
Precondition:	Activated object

With **Point cloud** text files containing point cloud data can be imported. An activated object must exist beforehand. Reading large files can cause long processing times. Details about the input are given in the same way as for the object elements in the import window, in particular also about the physical unit used.

After loading the point cloud can be managed under **Objects/Object properties/Point cloud**. It is not necessary to have previously created images.

When saving the project, no new file with imported point clouds is created, but only references to the file read in here are saved.

2.8.2 Triangular mesh

Menu:	Project → Import → Triangular mesh
Precondition:	Activated object

With **Triangular mesh** text files containing a 3D triangular mesh data can be imported. An activated object must exist beforehand. Reading large files can cause long processing times. The applied physical unit must defined under **Edit/Options/Formats**. Optionally existing triangles for the current object will be deleted.

The following input formats are supported:

PhoX Mesh (*.tin)	Default format used by PhoX when a project is saved
STL (*.stl)	Standard STL format

2.8.3 Add project

Menu:	Project → Import → Add project

The function **Add project** can load a PhoX project file and add it to the current project. It requires an already existing project. Attention: The import overwrites existing image objects, if the imported file contains images with already existing image numbers. Cameras, objects and stereo models are added to the existing lists without overwriting existing data. Exterior orientations are imported. It is not possible to add projects in external formats.

2.8.4 Images from project

Menu:	Project → Import → Images from project

Using **Images from project** can load images from an existing PhoX project file and add them to the current project. It requires an already existing project. After opening the imported project file, a list of all stored image numbers appears where the desired images can be selected.

If already existing image numbers should be loaded into the current project, a corresponding new numbering must be confirmed by the user. For new numbering, the next free image number is assigned to the image. Already existing images in the project will not be overwritten.

2.8.5 Point covariances

Menu:	Project → Import → Point covariances
Precondition:	Activated object

The function **Point covariances** imports covariances or cofactors of object points. The coefficients C_{ij} are the values of the covariance matrix, s_0 means Sigma 0 (standard error of unit weight). The imported matrix will be assigned to the loaded point.

The following input formats are available:

Covariance matrix A text file of the following format will be read:

```
Pt.No.      X          Y          Z
C11         C12        C13
C21         C22        C23
C31         C32        C33
```

The values $\sqrt{C_{ii}}$ of the principal diagonal are stored as standard deviations to the point. It is assumed that the imported covariance matrix was calculated by **Σ** = s^2_0 * **Q**.

Cofactor matrix + Sigma0 A text file of the following format will be read:

```
Pt.No.      X          Y          Z
s0
C11         C12        C13
C21         C22        C23
C31         C32        C33
```

The values of the cofactor matrix will be multiplied by s^2_0 to give the covariance matrix.

Confidence ellipses or confidence ellipsoids can be represented with the imported values, for example in the function **Graphics/Image footprints** or **Graphics/3D viewer**.

2.9 Export

Menu:	Project → Export
Precondition:	Loaded project

The **Export** menu item is used to store project data in external files.

2.9.1 Project

Menu:	Project → Export → Project

With the **Project** feature, project data can be exported. Currently the following output formats are available:

PhoX (*.pxp)	Output as PhoX project archive, see **Project/Save project as**
AICON (*.eor, *.ior)	Output as AICON format: Camera data (interior orientation) in the file *filename.ior* Exterior orientations in the file *filename.eor* Object coordinates in the file *filename.obc* Image coordinates in the file *filename.phc* Bitmap assignments in the file *filename.pin*

2.9.2 Image coordinates

Menu:	Project → Export → Image coordinates
Precondition:	Min. 1 existing image object

The function **Image coordinates** stores image coordinates of one or more images in pre-defined or free formats. The images are set in a list selection window. If *Active objects only* is selected there, only the activated points are stored. PhoX file format selection uses an internal format, otherwise the output format defined under **Edit/Options/General/Formats** is used.

Image coordinates (*.pho)	Image coordinates in the PhoX format: Image No. Point No. x' y' sx' sy' code
AICON (*.phc)	Image coordinates in AICON format: Image No. Point No. x' y' sx' sy' vx' vy' c1 c2 c3
Free format (*.txt)	Output with the format that has been defined under **Edit/Options/General/Formats** as output format for image coordinates.

2.9.3 Orientations

Menu:	Project → Export → Orientations
Precondition:	Min. 1 existing image object

With the function **Orientation**, the parameters of exterior orientation of one or more images can be saved in specified formats. The images are set in a list selection window. If *Active objects only* is selected there, only the data of active images is exported.

Currently the following output formats are supported:

PhoX (*.pxp)	Internal PhoX output format
AICON (*.eor)	AICON output format:
	Image No.,-999, X_0, Y_0, Z_0, ω, φ, κ, 0, 0, 0
EO + R (*.txt)	Output of the exterior orientation and the rotation matrix
	Image No., X_0, Y_0, Z_0, ω, φ, κ, r_{11}... r_{33}

2.9.4 Object elements

Menu:	Project→ Export → Object elements
Precondition:	Activated object

With the function **Object elements**, information of 3D objects can be stored in predefined or free formats. The output format is defined under **Edit/Options/General/Formats**. After calling the function, a dialog window will appear in which the 3D objects to be exported and the associated elements (points, polygons, etc.) are selected. Then, the output file and output format are set. Depending on the output format only certain items for export are allowed. If *Active objects only* is selected there, only the active objects and their active object points are saved.

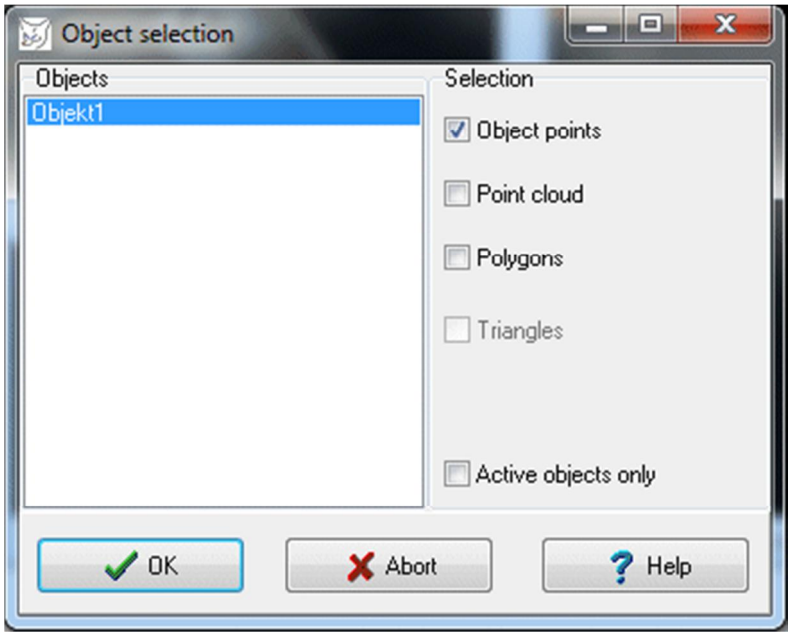


Fig. 15: Selection of object elements

Currently the following output formats are supported:

PhoX (*.xyz)	Object coordinates and polygons in the PhoX format
DXF (*.dxf)	Object coordinates and polygons in DXF format (not yet implemented)
Leica (*.mp)	Object coordinates in Leica LPS format

STL (*.stl)	Polygons or triangles in STL format
AICON (*.obc)	Object coordinates in AICON format: Point No., X, Y, Z, sX, sY, sZ, c1, c2, c3, c4
Excel (*.csv)	Object coordinates in the format that has been defined under **Edit/Options/General/Formats** ; single values are stored in country-specific format and separated by a semicolon
Free format (*.*)	Object coordinates in the format that has been defined under **Edit/Options/General/Formats**

2.9.5 Pointcloud

Menu:	Project → Export → Point cloud
Precondition:	Active object with point cloud

With the **Point cloud** function, 3D point clouds can be saved in specified formats as a text file. After calling up the function, a dialogue window opens in which the 3D object to be exported is selected. Then the output file and the output format are specified.

The following output formats are currently supported:

XYZ (*.*)	3D coordinates X, Y, Z
XYZ RGB (*.*)	3D coordinates X, Y, Z with colour values R,G,B in interval [0..255]

2.9.6 Triangular mesh

Menu:	Project → Export → Triangular mesh
Precondition:	Active object with triangular mesh

With the **Triangle meshing** function, triangle coordinates of a surface meshing can be saved in specified formats as a text file. After calling up the function, a dialogue window opens in which the 3D object to be exported is selected. Then the output file and the output format are specified.

The following output formats are currently supported:

PhoX Mesh (*.tin)	Internal PhoX format (for each triangle three lines with XYZ coordinates)
STL (*.stl)	Standard STL format

2.9.7 VRML

Menu:	Project → Export → VRML
Precondition:	Activated object

The function **VRML** allows storing of various object elements in VRML (virtual reality modeling language) format. Only those object elements are stored that belong to the current object. The selection of elements (points, textures, polygon, cameras, image rays) is defined under **Edit/Options/Visualisation/Objects.** The output file is set in a file dialog. It can be displayed with an external VRML viewer (e.g. BS Contact).

2.10 Exit

Menu:	Project → Exit

PhoX is terminated. If data or settings have been changed, the user is prompted to back up the project data.

3 Menu Edit

The **Edit** menu manages data for the clipboard and other settings.

3.1 Reset

Menu:	Edit → Reset
Button:	Esc

The current measurement mode is reset to the normal selection mode for all image windows. This function corresponds to the key Esc or the button  , but for all image windows simultaneously.

3.2 Copy

Menu:	Edit → Copy
Button:	Ctrl C
Precondition:	Selected image area

The **Copy** function copies a rectangular image that is drawn with the mouse to the Windows clipboard. From there the data can be copied into a new image window by **Edit/Paste**. The cached image section can be transferred directly into other programs as a bitmap object, if these allow inserting images from the clipboard. If no rectangular window has been defined by the mouse, the entire image is copied.

3.3 Paste

Menu:	Edit → Paste
Button:	Ctrl V
Precondition:	Previously copied image area

The function **Paste** inserts an image frame from the Windows clipboard into a new image window. Note: Excerpts from original images have no defined relation to a camera or an interior orientation.

3.4 Copy image graphics

Menu:	Edit → Copy image graphics
Precondition:	Opened image window

The **Copy image graphics** function copies the image visible in the image window image with all superimposed graphics to the Windows clipboard, for example with superimposed image points.

3.5 Options

Menu:	Edit → Options
Button:	

The function **Options** offers multiple input pages for program settings. The desired page is displayed by clicking on the links in the displayed directory. The settings are accepted with the button OK. With Cancel the window closes without changes.

With Save the current settings will be saved to the file PhoX.ini. The button Default restores the default values of the settings.

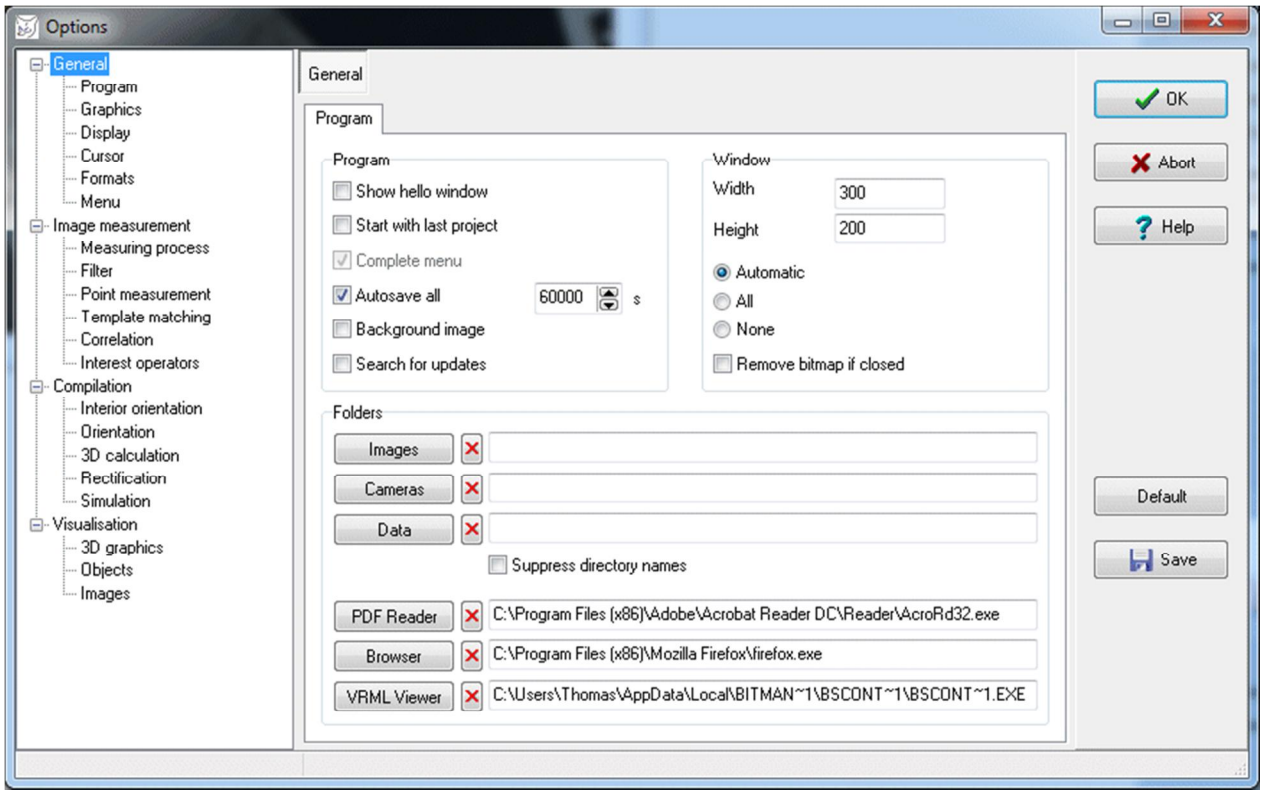


Fig. 16: Options: General / Program

3.5.1 Program

Menu:	Edit → Options → General → Program

The page **Program** (Fig. 16) contains general settings for the program.

Program:

Show hello window: displays a window with details of the program at startup

Start with last project: the most recently edited project is automatically loaded when the program starts

Auto save: The program performs an auto-save of the project data in the specified time interval. These files are created with the name "$Backup_" and the attached name of the project file in the current project directory.

Search for updates: checks whether a newer version is available at program startup.

Window:

For the menu function **Windows/Arrange** the image windows are displayed in the size defined by *width* and *height*.

automatic: when loading project files related images are displayed in an image window, if they were visible before.

All: All loaded images are displayed in image windows. This option may result in significant memory usage for very large image volumes.

None: no bitmaps are loaded and the images are not displayed.

The option *Remove bitmap if closed* removes the bitmap from an image object when the image window is closed.

Directories: File directories for images, cameras and data can be entered here and used when importing a project file (see **Project/Open project**).
The programs to display the PDF help file (PDF reader), to open Internet pages (browser) and to view VRML files (VRML viewer) are usually determined by the program itself. Experienced users can enter own settings for the path to an executable program.

If the option *Suppress directory names* is enabled, no absolute path names are saved with the project file, i.e. files connected with the project are stored with their file name only.

3.5.2 Graphics

Menu:	Edit → Options → General → Graphics

The page **Graphics** contains parameters for the graphical output of various elements.

For all listed graphic objects, the following settings can be defined:

Display: The selected objects appear in the displayed color if the box is selected. This switch controls the overall display of the items. In addition, the individual appearance of points, polygons, point clouds and triangles is defined under Object properties.

Pattern: The selected object is represented with a fill pattern or a line style from the drop-down list.

Size: Numeric value of the marker size or line width

Miscellaneous: Different additional options, e.g. annotation of point numbers (*Caption*).

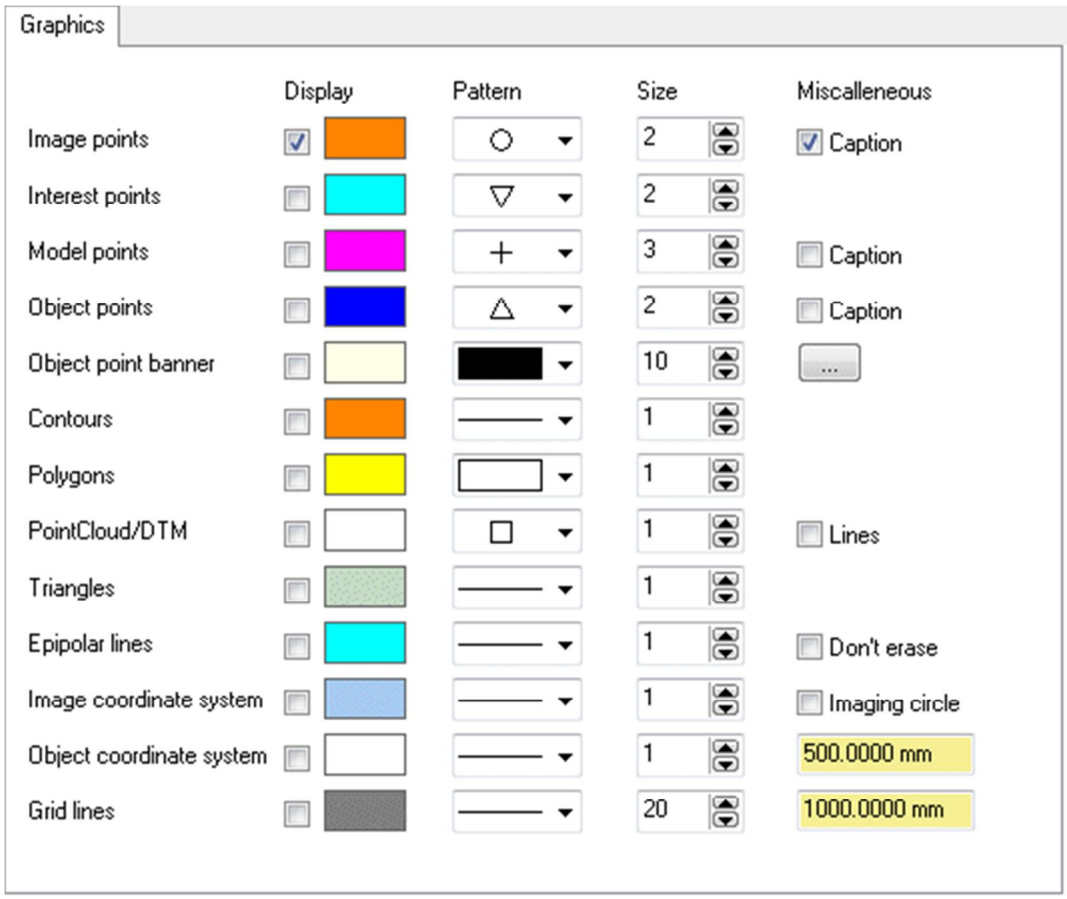


Fig. 17: Options: General / Graphics

In particular, values for the following objects can be set:

Image points: Display of the image points which are saved to an image

Interest points: Display of feature points which are measured by an interest operator

Model points: Display of the model points of the selected stereo model

Object points: Display of the object points which are stored in 3D objects

Object point banner: Display of a banner next to the object points with additional information which can be selected by the button [...]. The *Size* parameter sets the distance of the banner from the point. Displayable information is: point number, XYZ coordinates, deformations (standard deviations sX, sY, sZ), distance from object point to camera, image scale and pixel resolution (GSD) in object space.

Contours: Display of the contours that are saved to an image

Polygons: Display of the polygons that are stored in the 3D objects

Point cloud/DTM: Display of the point cloud which is stored in the 3D objects

Triangles: Display of the triangles which are stored in the 3D objects for a meshing

Epipolar lines: Display of epipolar lines for the measurement of object coordinates under **Measure/Object coordinates**

Image coordinate system: Display of the image coordinate axes and the principal point position

Object coordinate system: Display of the 3D object coordinate system with XYZ axes. The length of the axes is set by the right input field.

Grid lines: Display of a coordinate grid in the XY object plane. The grid lines begin at the origin of the object coordinate system and are repeated in both directions *n* times, where *n* is the value specified in *Size* (10). The grid has the extension of the length of the XYZ axes defined above. The length of the grid lines perpendicular to the coordinate axis is set in the right input field.

3.5.3 Display

Menu:	Edit → Options → General → Display

The page **Display** contains parameters for the numerical output of physical quantities and the display of error or deformation vectors.

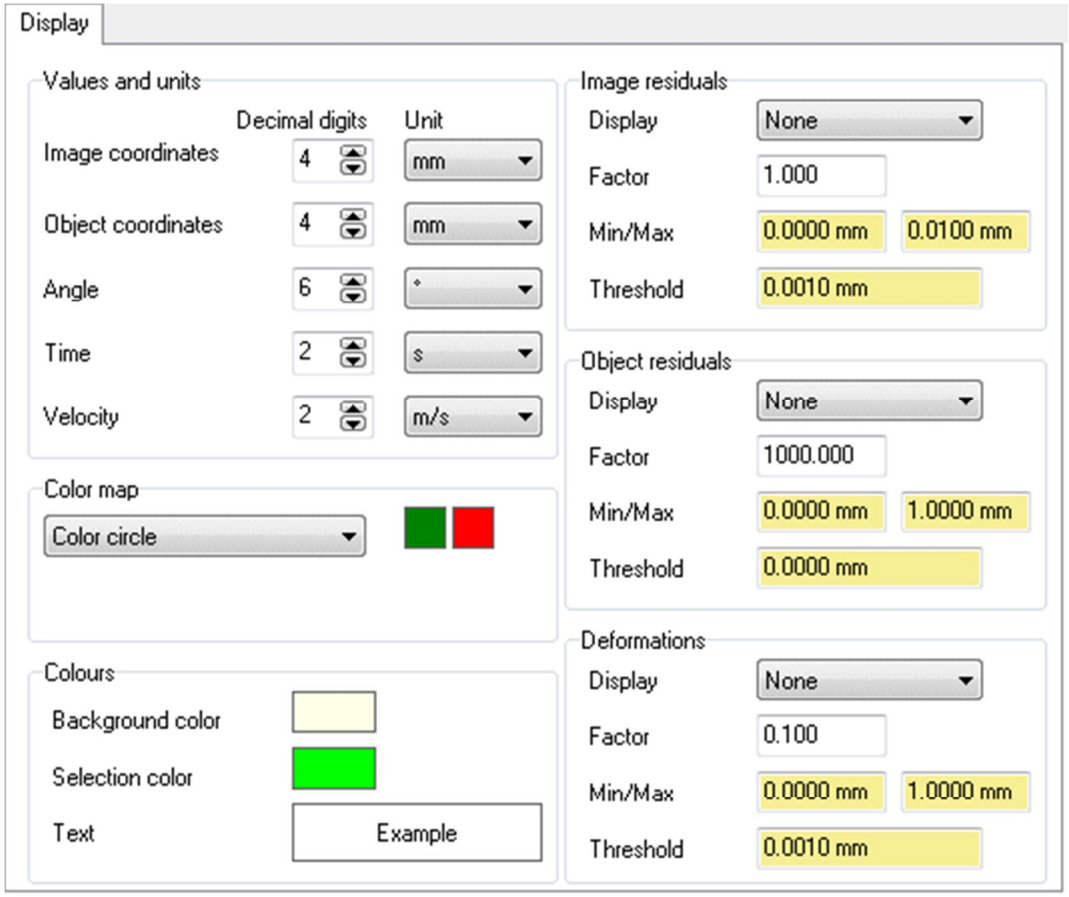


Fig. 18: Options: General / Display

Under Values and units the number of decimal digits and the physical unit of output settings can be set:

Image coordinates: Selection: µm, mm, m, km, "(inch), ft (feet), %;
default: 4 digits, mm

Object coordinates: Selection: µm, mm, m, km, "(inch), ft (feet), %;
default: 4 digits, m.

Angle: Selection: °(degrees), gon, rad, dms (degrees/min/ sec), mm/m
default: 6 digits, degree

Time: Selection: s, m, h, d, a
default: 2 digits, second

Velocity: Selection: m/s, km/h, mph
default: 2 digits, m/s.

Under Image residuals the output of residual errors in the image is defined (standard deviations of image coordinates). The color of the residual error indicates a color value of the Color map described below.

Display: Type of error representation
None: residuals are not displayed
Vectors: residuals are drawn as vectors
Ellipses: residuals are drawn as non-rotated ellipses (semi-axes = residuals)
Ellipsoids: not available

Factor: Scale factor for error values.

Min/Max: Minimum and maximum error values associated with the color map.

Threshold: When using the color scale of type *Two colors*, the value from which the errors are displayed in the second color (red). Otherwise they appear in the first color (here green).

Under Object residuals the output of residual error of the object coordinates (standard deviations of the object coordinates) is defined. The color of the residual error indicates a color value of the Color scale described below. In two-dimensional outputs the choice of the coordinate directions (e.g. XY) is done within the graphics output function.

Display: Kind of error display
None: residuals are not displayed
Vectors: residuals are displayed as vectors
Ellipses: residuals are displayed as non-rotated ellipses (semi-axes = residuals)
Ellipsoids: residuals are displayed as confidence ellipses based on the imported covariances or eigenvalues

Under Deformations also corresponding display values are defined. This is the representation of deformation vectors between identical points of all objects stored in the object list. This can be, for example, 3D coordinates from different periods of deformation.

Display: Kind of error display
None: deformation vectors are not displayed
Vectors: Deformation vectors
Ellipses: not available
Ellipsoids: not available

Under Color map the color palette is selected that is used in various visualizations for color-coded representations of the range of values. Available options are:

Color circle:	Color palette containing all colors of the color circle
Blue-Green-Red:	Color palette starts at Blue and ends at Red with Green in the middle
Rainbow:	Color range corresponding to the colors of a rainbow
Two colors:	Two-tone color palette in the colors displayed in the right panels
Color interpolation:	Color palette with a continuous gradient between the colors displayed in the right panels
Color:	The color displayed in the left color field is used for display, regardless of any thresholds or min/max values

Under Colors the following parameters are adjusted:

Background color:	Background color in the 3D viewer or for image rectifications
Selection color:	Color of the selected items
Text:	With the button Example the current font, font size, and color are chosen, labeled with the graphic objects in the images or diagrams.

3.5.4 Cursor

Menu:	Edit → Options → General → Cursor

The page **Cursor** contains parameters for the choice of a cursor or a measuring mark.

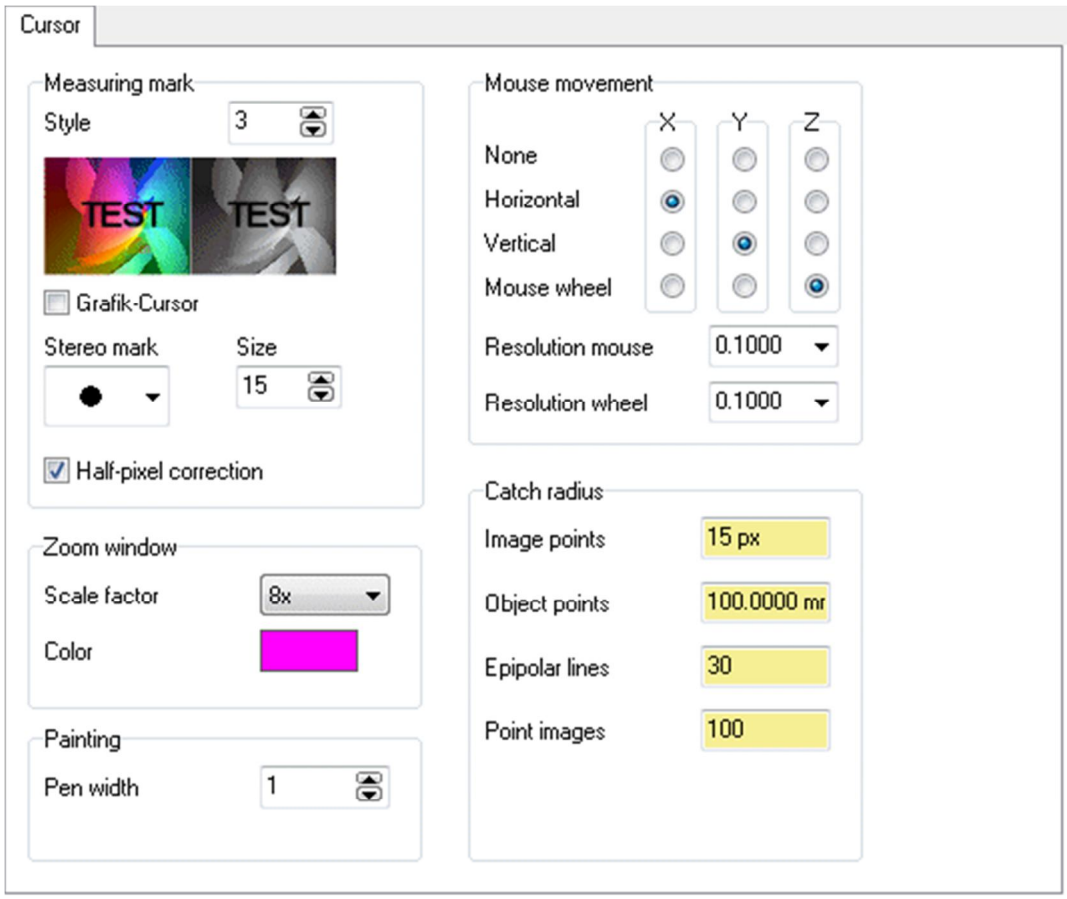


Fig. 19: Options: General / Cursor

Under Measuring mark the shape of the cursor used in the measurement of image points is defined.

Style Selection of various system cursors. The cursor effect can be tested over the displayed sample image.

Graphic cursor If this option is enabled, are rectangular cursor is displayed in the size of the search window associated to the select measurement algorithm. The color of the rectangle is equal to the cursor color defined under Zoom window.

Stereo mark Selection of different cursor shapes of specified *Size*, used when measuring with the spatial floating mark in stereo mode.

Half-pixel correction Shifts image markers (e.g. measured image points) by +0.5 pixel and corrects manually measured image coordinates by -0.5 pixel.

Under Zoom window settings for the zoom window are made that can be opened with the right mouse button or the Ins key for a displayed image window.

Scale factor Factor for the magnification of the image window

Color Color of the cursor displayed in the zoom window

Under Mouse movement settings for the mouse movements of the spatial floating mark are specified. The displayed table enables the assignment of mouse movements to the spatial coordinates X, Y, Z of the spatial floating mark.

Resolution mouse Factor to the translation of the mouse movement

Resolution wheel Factor to the translation of the mouse wheel

The increments of the spatial floating mark are defined on page 3D calculation.

Under Painting settings for manual drawing or modification of pixel values in image are made.

Pen width Width of the brush

Under Catch radius tolerance settings for working with the cursor are defined.

Image points Size of the catch area where points can be selected by clicking into the image.

Object points Size of the catch area, where object points can be selected by clicking into the image.

Epipolar lines Width of the band in pixels along an epipolar line, in which the measuring cursor for the measurement of object points can be moved.

Point images Size of a square image, which is stored as a point image.

3.5.5 Formats

Menu:	Edit → Options → General → Formats

The page **Formats** contains parameters for the file formats of various input and output data. Only text files (ASCII format) with one point per line can be processed.

Image coordinate files can contain the following values:

Image number (I)	Integer
Point number (P)	Integer
Image coordinate x' (X)	Double
Image coordinate y' (Y)	Double
Measurement uncertainty sx' (x)	Double
Measurement uncertainty sy' (y)	Double
Attribute (c)	Integer

Object coordinate files can contain the following values:

Point number (P)	Integer
Object coordinate X (X)	Double
Object coordinate Y (Y)	Double
Object coordinate Z (Z)	Double
Measurement uncertainty sX (x)	Double
Measurement uncertainty sY (y)	Double
Measurement uncertainty sZ (z)	Double
Attribute (c)	Integer

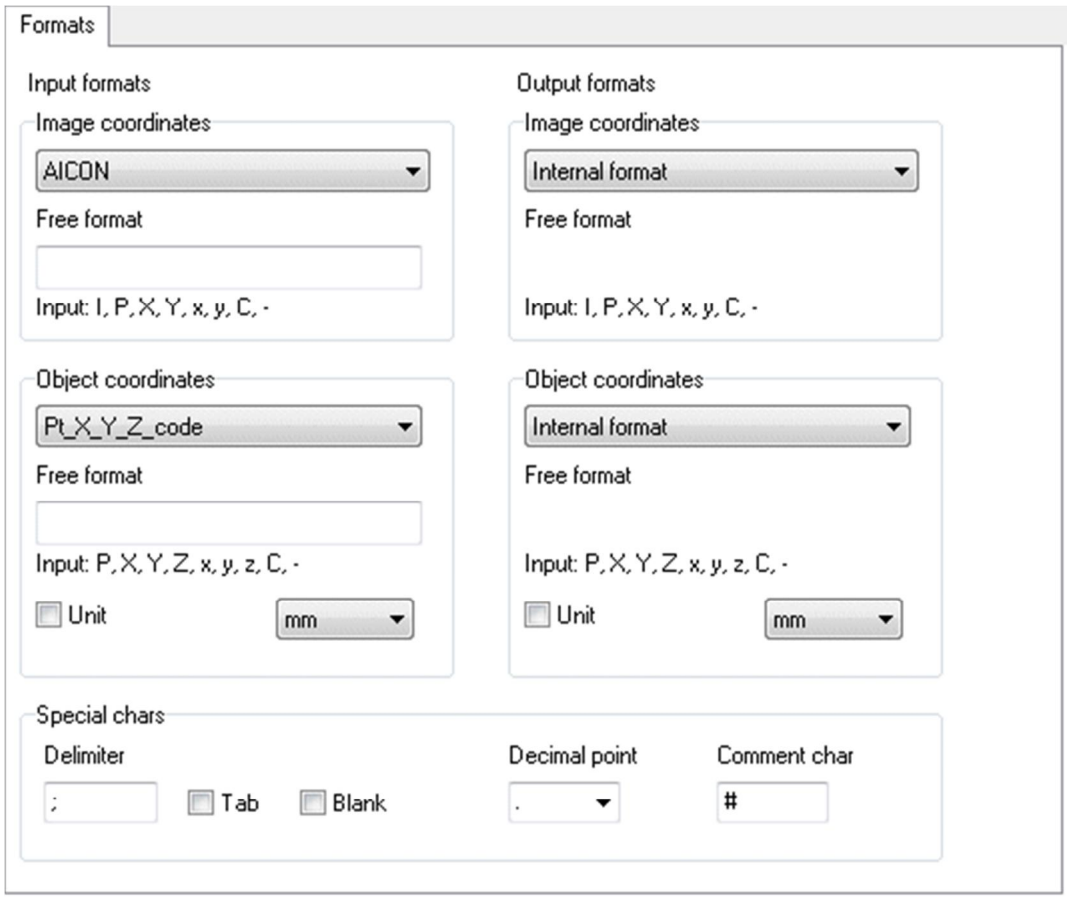


Fig. 20: Options: General / Formats

Under Input formats the settings are specified that are required to read image or object coordinate files.

Under Image coordinates input formats for image coordinate files are set.

Internal format: Is used for the storage of internal project files

Free format: Any definition of a row according to the pattern given in the text box

For example, `I, P, _, X, Y, x, y`

This a file line with expected image number, point number, a value to be skipped, image coordinate x', image coordinate y', measurement uncertainty sx', measurement uncertainty sy'

Other available formats include fixed value orders or product-specific input formats.

Under Object coordinates input formats for object coordinate files are set.

Internal format: Is used for the storage of internal project files

Free format: Any definition of a row according to the pattern given in the text box

For example, `P, X, Y, Z`

This a file line with expected point number, object coordinate X, object coordinate Y, object coordinate Z

Other available formats include fixed value orders or product-specific input formats.

Unit defines the physical unit of length, in which the coordinates of the input file are defined. When *Unit* is turned on, the input data is interpreted in the selected physical unit.

Under Output formats, the settings are defined accordingly, that are required to write the image or object coordinate files. Free formats are not currently supported when writing files.

With Special chars, additional properties of the input files are defined.

Delimiters	any ASCII character which separates the values to be read (default: space). If the option *Tab* is activated, only tab characters are accepted as delimiters.
Decimal point	can either be a decimal point (e.g.: 3.124) or a comma (e.g.: 3,124).
Comment characters	are those characters that appear as the first character of an input line to mark a comment line (default: #).

3.5.6 Menu

Menu:	Edit → Options → General → Menu

On the page **Menu** the items of the main menu of PhoX can be switched visible or invisible, and can be associated to the custom toolbar.

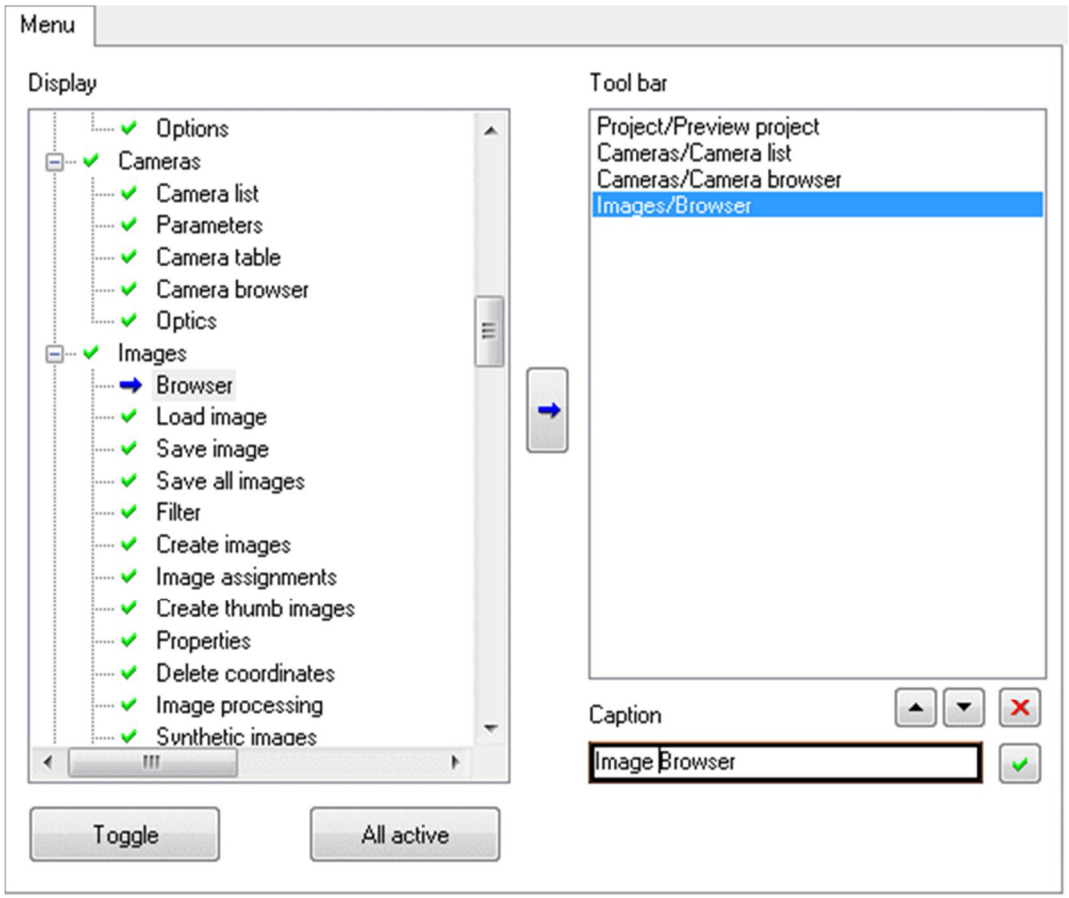


Fig. 21: Options: General / Menu

The menu item selected under *Display* in the project tree can be switched visible or invisible with button Toggle. Important menu items, which must be always visible, cannot be changed.

With the button ➡ a selected menu item can be transferred to the toolbar. The toolbar is a customizable toolbar with large button symbols, which can directly be used to run a menu function. Each button can have an individual label, which is defined by the *Caption* input field below. The selected settings are stored in the layout file of the project and are available at the next program start again.

3.5.7 Measuring process

Menu	Edit → Options → Image measurement → Measuring process

The page **Measuring process** contains options for the workflow of image point measurement by automatic image processing methods.

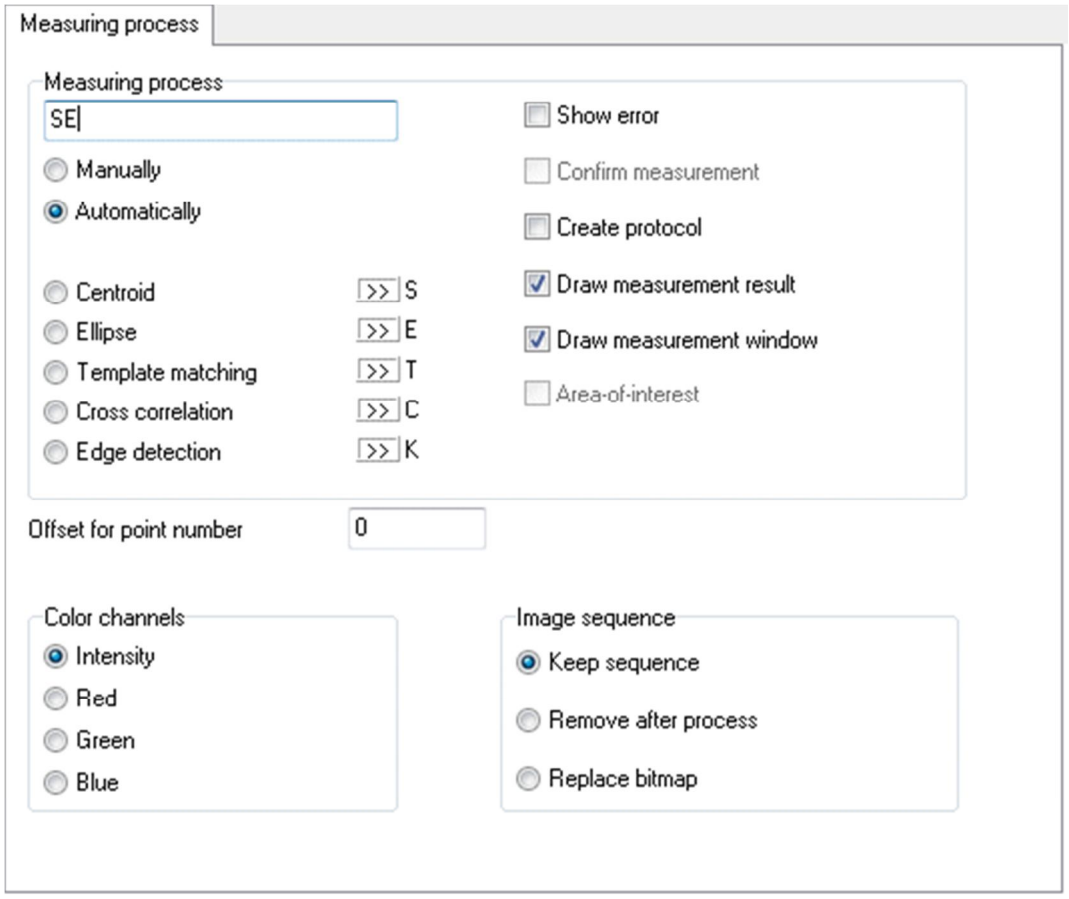


Fig. 22: Options: Image measurement / Measuring process

The settings for *Measuring process* have the following meaning:

Manually: The image point is measured manually by clicking on a point with the mouse

Automatically: The image point measurement follows a measurement procedure as it is entered in the text field by a series of characters. As an example, the input of characters 'SE' means that a point is measured with a centroid operator (*S*) followed by an ellipse operator (*E*). The corresponding shortcuts can also be generated directly with buttons >>. The image coordinates obtained from a first operator are entered as starting values for the following measurement.

Centroid: The image point (usually white on a dark background) is determined through the centroid (center of gravity) of the grey values in the measurement window. Shortcut: *S*

Ellipse: The image point (usually circular bright target) is measured by the contour points of the edge of the target and a subsequent best-fit ellipse that is calculating the point center. Shortcut: *E*

Template matching: Measurement of any pattern by least-squares matching of a template image. Shortcut: *T*

Cross correlation: Measurement of any pattern by normalized cross-correlation of a template image. Shortcut: *C*

Edge measurement: Measurement of an edge point. Shortcut: *K*

The other options control the output and display of measurement results:

Show error: Output of a message if an error occurs during point measurement

Confirm measurement: Not implemented

Create output log: Creates a text file with intermediate results and details of the point measurement

Draw measurement result: Graphical display of edge points or other information into the image to control or visualize measurement results

Draw measurement window: Display of the image area with graphical measurement results in the docking window **Measure/Image coordinates** and in a new image object "DebugImage" that appears in the image list after measurement.

Area of interest: Not implemented

The point numbers of measured image points are increased with the integer value for *Offset for point number*.

Under Color channels the color channel of an image is specified that is used for the automatic point measurement.

All: From all color channels, the mean intensity value is calculated and used for the measurement.

Red, Green, Blue: The selected channel is used for the measurement.

Under Image sequence it will be defined how an image sequence belonging to the image, e.g. generated by an image batch process, is managed according to the process. The images of the sequence can be managed under Image properties.

Keep sequence: All images in the image sequence are retained and not deleted.

Remove after process: The sequence of images will be deleted after the batch processing.

Replace bitmap: The current bitmap of the image object is replaced by the last image of the sequence.

3.5.8 Filter

Menu	Edit →Options → Image measurement → Filter

The **Filter** page contains options for image filtering in the measurement of points by automatic image processing methods. This function has not been finally tested.

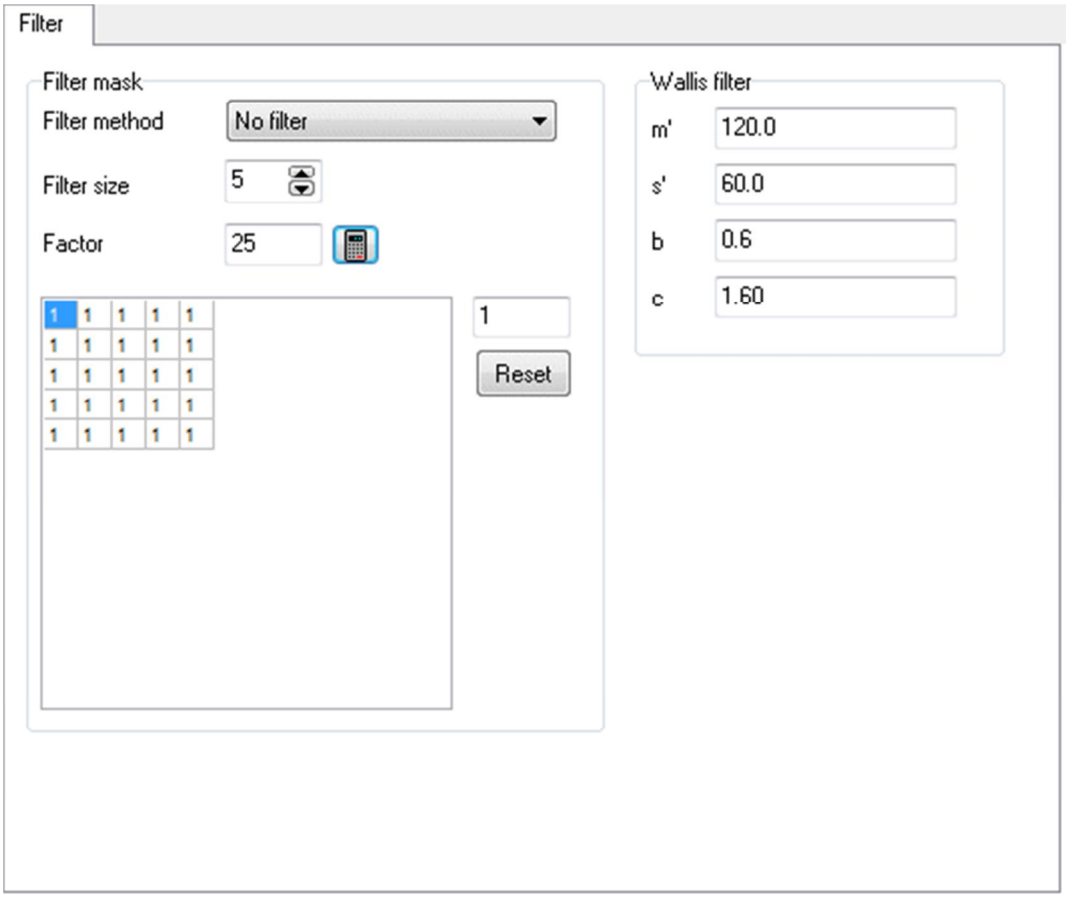


Fig. 23: Options: Image measurement / Filter

Under Filter mask the size and coefficients of a filter operator are defined.

Filter method Predefined convolution filters
No filter: a filter is not applied

Filter size Size of the filter matrix (odd integer)

Factor Integer value for division of the convolution sum. With the factor can be calculated from the entered filter coefficients.

With Reset the filter mask will be filled with the value defined in the input field above.

Under Wallis Filter parameters of a Wallis filter are defined. The Wallis filter adjusts the contrast of an image and can be executed under **Images/Image processing**.

3.5.9 Point measurement

Menu	Edit → Options → Image measurement → Point measurement

The **Point measurement** page contains options for different operators for the measurement of points by automatic image processing methods.

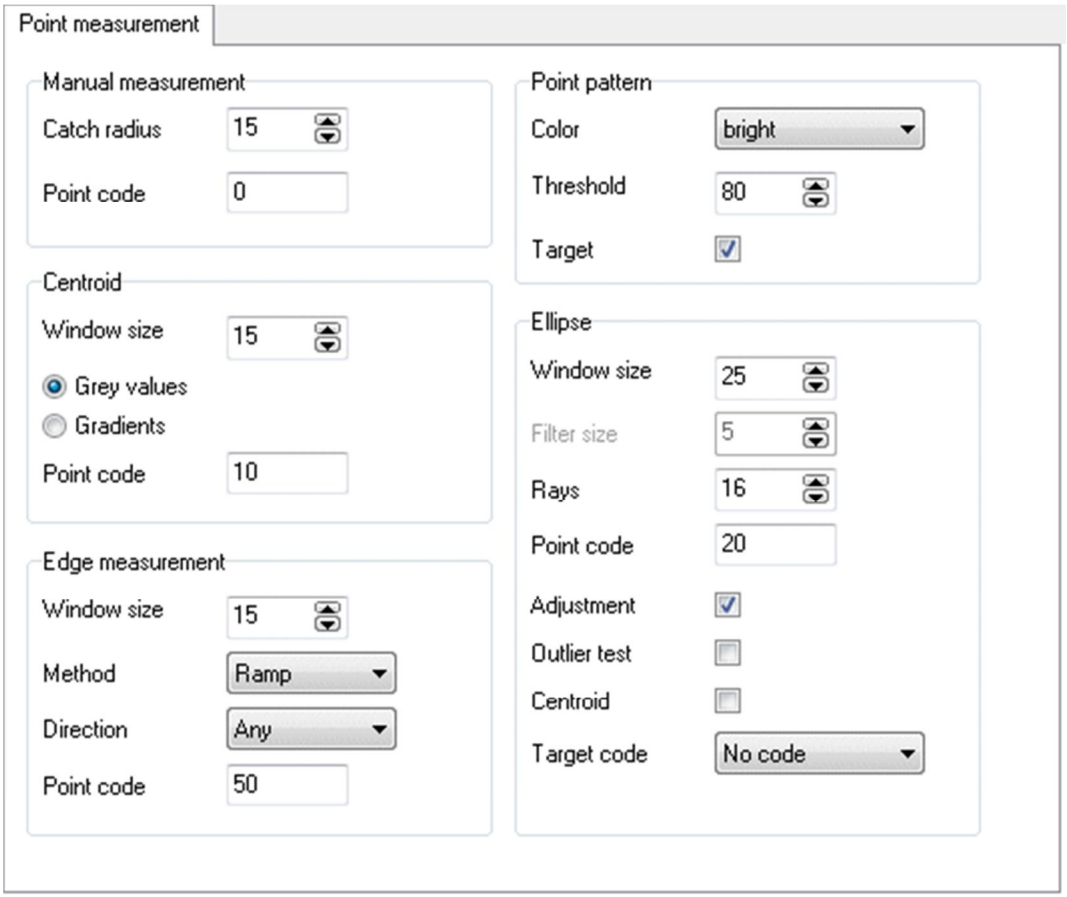


Fig. 24: Options: Image measurement / Point measurement

Settings for the Manual measurement of image points include:

Catch radius Size of the capture area in pixels when clicking into the image to select a point.

Point code Code (integer) of a manually measured point.

Under Point pattern options for segmentation of point patterns, as well as for the definition of the pattern color are given:

Color Selection of the color of a target to be measured automatically.
bright: bright (white) target on a dark background
dark: dark (black) target on a bright background

	red, *green*, *blue*: red, green, or blue target on a different background *any*: the color of the target does not matter (not yet implemented).
Threshold	Minimal (for bright) or maximum color value (for dark targets) of the pattern; input of -1 enables an automatic determination of the threshold.
Target:	For the *Centroid* and *Ellipse* operators a mask is calculated in advance that marks only those pixels which correspond to the selected Color channel and the target properties defined under Point measurement > *Point pattern*. With this option, the point measurement can be conducted more robustly.

Under Centroid settings for applying a centroid operator are made:

Window size	Size of the window in pixels in for the centroid calculation
Point code	Code (integer) of the measured point
Grey values	The centroid is calculated with the grey values of the image window
Gradient	The centroid is calculated with the gradients of the image window

Under Ellipse settings for an ellipse operator (star operator) are defined:

Window size	Length of the search beams of the star operator
Filter size	Size of the filter matrix for determining edges (currently fixed to 5)
Rays	Number of search rays of the star operator
Point code	Code (integer) of the measured point
Adjustment	Calculation of a best-fit ellipse
Outlier test	Elimination of outliers for the best-fit ellipse
Centroid	Ellipse center is calculated as a centroid of the best-fit ellipse
Coded target	Automatically determines the corresponding point number for the selected encoding (not finally implemented)

Under Edge measurement settings for an edge operator are defined:

Window size	Size of the search area perpendicular to the edge
Method	Style of the edge: *Ramp*: locates the edges point at a bright-to-dark change *Line*: searches the local extremum of the brightness such as the center of a thin line,
Direction	Search direction of the operator: *Any*: locates the edges point along the horizontal, vertical and two diagonal directions in a search environment of the length of *Window size* * 2, and uses the edge point with the largest absolute gradient; *Horizontal*: locates the edge within a horizontal search environment of the length of *Window size* * 2, i.e. a vertical edge can be detected *Vertical*: locates the edge within a vertical search environment of the length of *Window size* * 2, i.e. a horizontal edge can be detected.
Point code	Code (integer) of the measured edge point

3.5.10 Template matching

Menu	Edit → Options → Image measurement → Template matching

The page **Template matching** provides options for the measurement of image points by least-squares template matching. With template matching, the original image is adapted to a sample image (template) by least-squares adjustment, and thereby determines a geometric transformation (affine transformation) with linear radiometric adjustment. The center of the image pattern is revealed by the translation parameters of affine transformation.

Under Templates the actual template bitmap can be read. An arbitrary number of templates can be loaded. The template currently to use is set in the drop-down list and displayed right next to it. In addition to the template, a weight thumbnail can be read, which must have the same size as the template. The higher the grey value in the weight image, the higher is the weight of the corresponding pixel. Depending on the activation of the option *Template* or *Weight image* the according image file is read through the button File. With Delete the template or weight image can be removed from the list. *Point code* specifies the code for the measured image point.

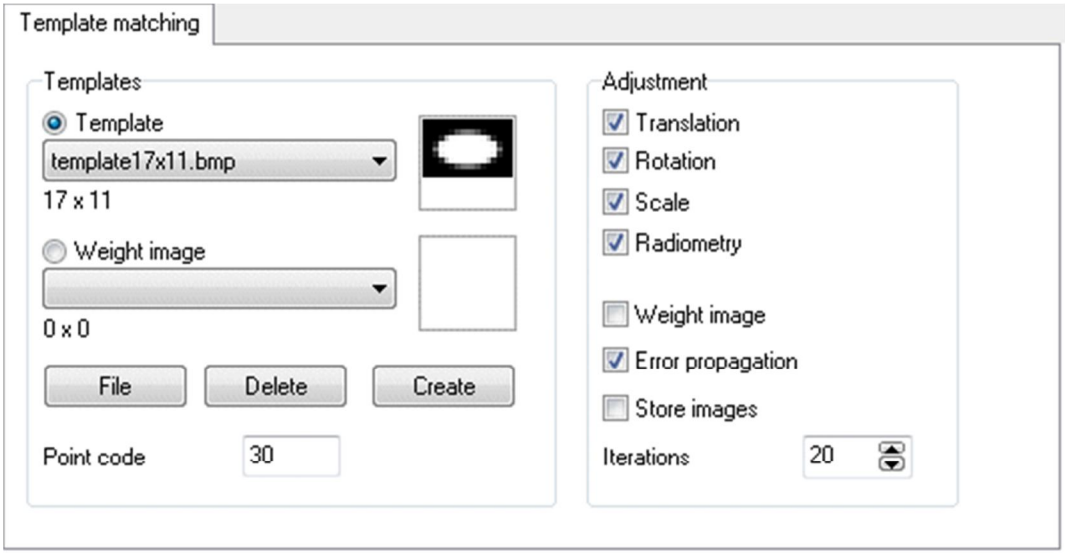


Fig. 25: Options: Image measurement / Template matching

With Create a template or weight image can be created. Then the following dialog is opened.

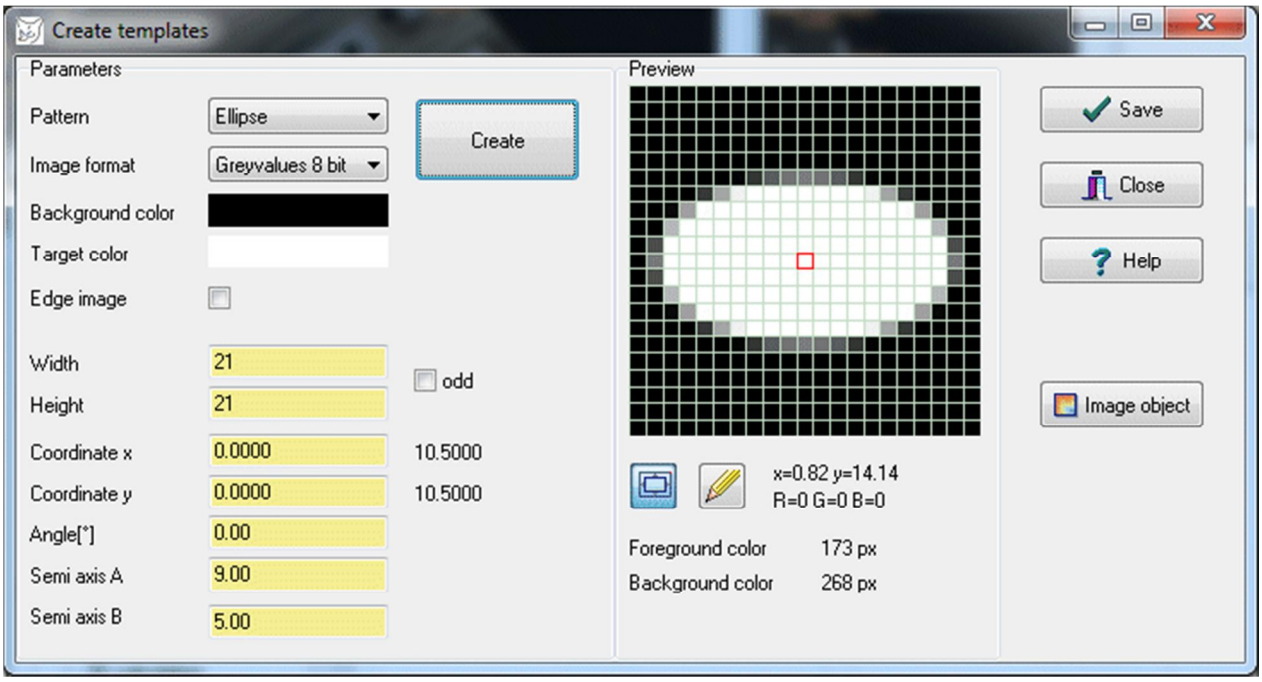


Fig. 26: Dialog for generating synthetic templates

In this dialog, the *Pattern* to be created is selected from a list and the corresponding geometric and color values are defined.

Image format: Grey values (8 Bit) or RGB values (24 Bit)

Background color: Color of the background

Target color: Color of the target

Edge image: Creates a gradient (edge) image of the template

Width/Height: Size of the template in pixels. If the option *Odd* is enabled, the size is automatically set to an odd number of pixels.

Coordinate x,y: Shifts the template from the image center in pixels. The resulting center coordinates appear right.

Angle [°]: Rotation angle of the pattern

Semi- axes a/b: Size of the semi-axes of the pattern in pixels. Depending on the selected *Pattern*, the parameters *semi- axes a/b* are replaced by other values.

With Create the template image is generated and displayed under Preview. Alternatively a bitmap can be loaded from the Windows clipboard with Paste. In the preview area the image can be enlarged or painted with the pen function in the current colors (left mouse button: target color; right mouse button: background color). With Save a file dialog opens where the name of the template image file is specified. After saving the file, the generated template is automatically included in the template list. With Image object the generated template is stored as a new image object but not saved as a file.

Under Adjustment it will be defined which parameters of affine transformation and radiometric adjustment are calculated.

Translation Calculation of shift parameters of the affine transformation.

Rotation	Calculation of rotation and shear parameters of the affine transformation.
Scale	Calculation of scale parameter of the affine transformation.
Radiometry	Calculation of contrast parameters.
Weight image	Specifies whether a loaded weight image is used. Then the grey values of the weight image, which must be identical to the template in size, are used as weight in the adjustment.
Error propagation	Defines whether a complete error statistics is calculated in the adjustment. As a result, a standard deviation can be specified for each matching, which can be reported in the window **Measure/Image coordinates** after the measurement.
Store images	Is used to store the search image snippets transformed during an iteration in BMP format to the current project directory.
Iterations	The maximum number of iterations of the adjustment; the process will be stopped after this number is reached.

Interim results of the iterative adaptation can be displayed in the window **Measure/Image coordinates** when the option *Draw measuring window* is enabled under **Edit/Options/Image measurement/Measurement process**.

3.5.11 Correlation

Menu:	Edit → Options → Image measurement → Correlation

The **Correlation** page contains options for the measurement of image points by normalized cross-correlation. With correlation, a reference image (template) is compared with the current image content of a search window which determines the correlation coefficient between search and reference image for any location. The position of the highest correlation coefficient yields the desired center of the image pattern.

The reference image currently to use is set in the drop-down list and displayed right next to it. The list contains the templates read in the page Template matching. The size of the search window must be at least the size of the reference image. The *Step width* indicates the amount of pixels how the reference window is shifted above the search window. *Point code* specifies the code for the measured image points.

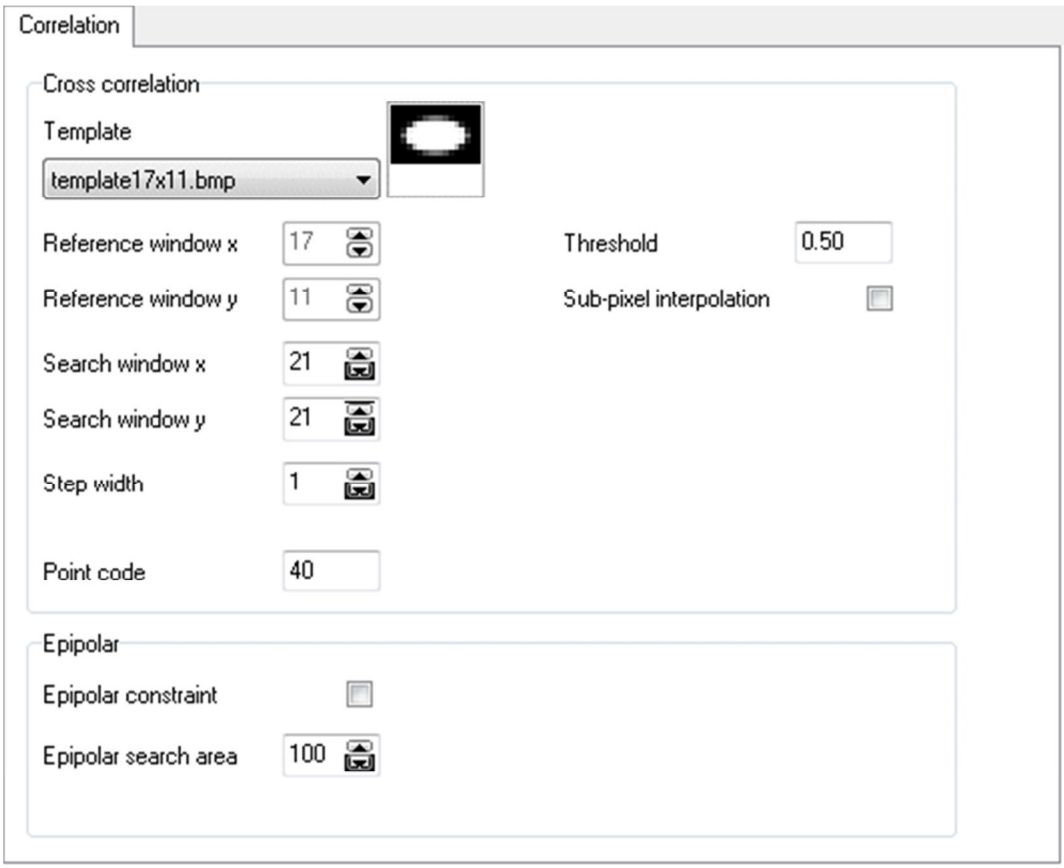


Fig. 27: Options: Image measurement / Correlation

Subpixel interpolation determines whether a sub-pixel location is calculated by the neighbouring correlation coefficients. The entered *Threshold* value defined the minimum correlation coefficient to be accepted in the calculation.

Under Epipolar options for epipolar constrains in stereo matching can be defined:

Epipolar constraint Activates the constraint

Epipolar search area Size of the buffer area along an epipolar line where matching is accepted

3.5.12 Interest operators

Menu	Edit → Options → Image measurement → Interest operators

The page **Interest operators** contains options for the detection of image points by interest operators. Interest operators find feature points in the image, which can be located with high probability as corresponding points in other images. One or more feature values are stored to the detected point of interest. The interest points are stored per image in a separated list.

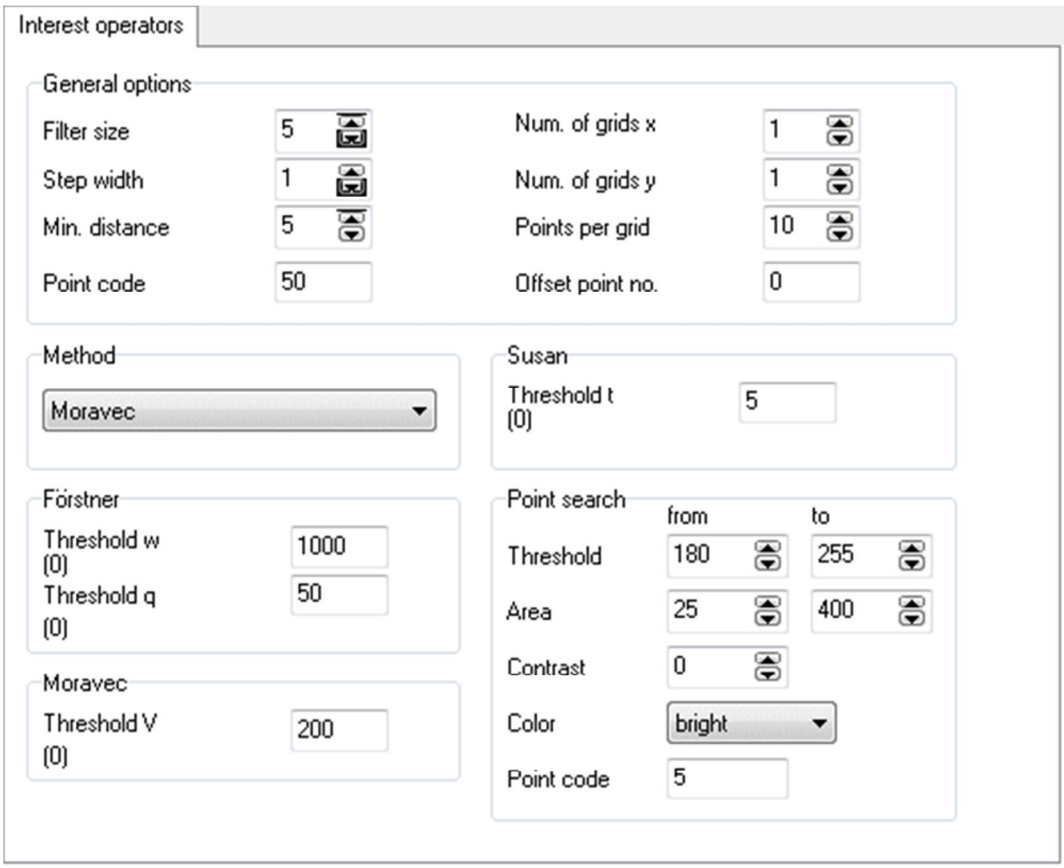


Fig. 28: Options: Image measurement / Interest operators

Under General options the following values can be defined:

Filter size	Size of the square filter window for the calculation of the interest operator
Step width	Increment used to move the filter window over the image
Min. distance	Minimum distance between detected interest points
Point code	Point code for the stored interest points
Num. of grids x, y	Horizontal or vertical number of grids where in each a maximum number of points is determined
Points per grid	Maximum number of interest points in one grid
Offset Point no.	Count offset to the point number

Under Method the required procedure for the measurement of interest points is selected:

Moravec	Moravec operator
Förstner	Förstner operator
Susan	SUSAN operator
Targets	Operator for the segmentation of point-shaped markers

Under Förstner settings for the Förstner operator are made:

Threshold w	Threshold value for the *w* parameter of the operator, which must at least be achieved. The value in parentheses is the maximum occurring value observed in a previous measurement.
Threshold q	Threshold value for the *q* parameter of the operator, which must at least be achieved.

Under Moravec settings for the Moravec operator are defined:

Threshold V Threshold value for the *V* parameter of the operator, which must at least be achieved. The parameter represents the minimum sum of gradients that must exist in the four main directions around one pixel.

Under Susan settings for the SUSAN operator are made :

Threshold t Threshold for the *t* parameter of the operator, which must at least be achieved.

Under Point search settings for detection of circular targets are made:

Threshold Range in which the grey values of the target pattern must be.

Area Minimum and maximum number of pixels of the target pattern.

Contrast Minimal contrast (difference between maximum and minimum grey value of the target pattern).

Color Color of the pattern (bright, dark, red, green, blue, any)

Point code Point code for the stored points.

3.5.13 Interior orientation

Menu	Edit → Options → Compilation → Interior orientation

The page **Interior orientation** contains options for defining the interior orientation of the image and the use of calibration parameters.

Under Pixel definitions the definition of the pixel coordinate system is made.

Pixel system *Default:* The pixel coordinate system has its origin in the upper left corner of the upper left pixel. Pixel coordinates can be interpreted as the distance from that origin, i.e. the maximum coordinate corresponds to the number of pixels in row or column direction.
Aicon: like default (is retained only for compatibility reasons)

Pixel correction *None*: pixel coordinates are processed without correction
+0.5: one half pixel is added to the pixel coordinates
-0.5: one half pixel is subtracted from the pixel coordinates.

Under Correction of image coordinates the applicable parameters of the interior orientation are defined.

Parameter *All:* All parameters of the associated camera model of interior orientation are applied.
None: no parameters are applied
Selection: The parameters marked under *Selection* are applied.

Selection The selected parameters will be considered in the interior orientation.

Epipolar lines with distortion:

In the graphical representation of epipolar lines (see also

Edit/Options/General/Graphics) curves are drawn instead of straight lines by taking the distortion parameters into account.

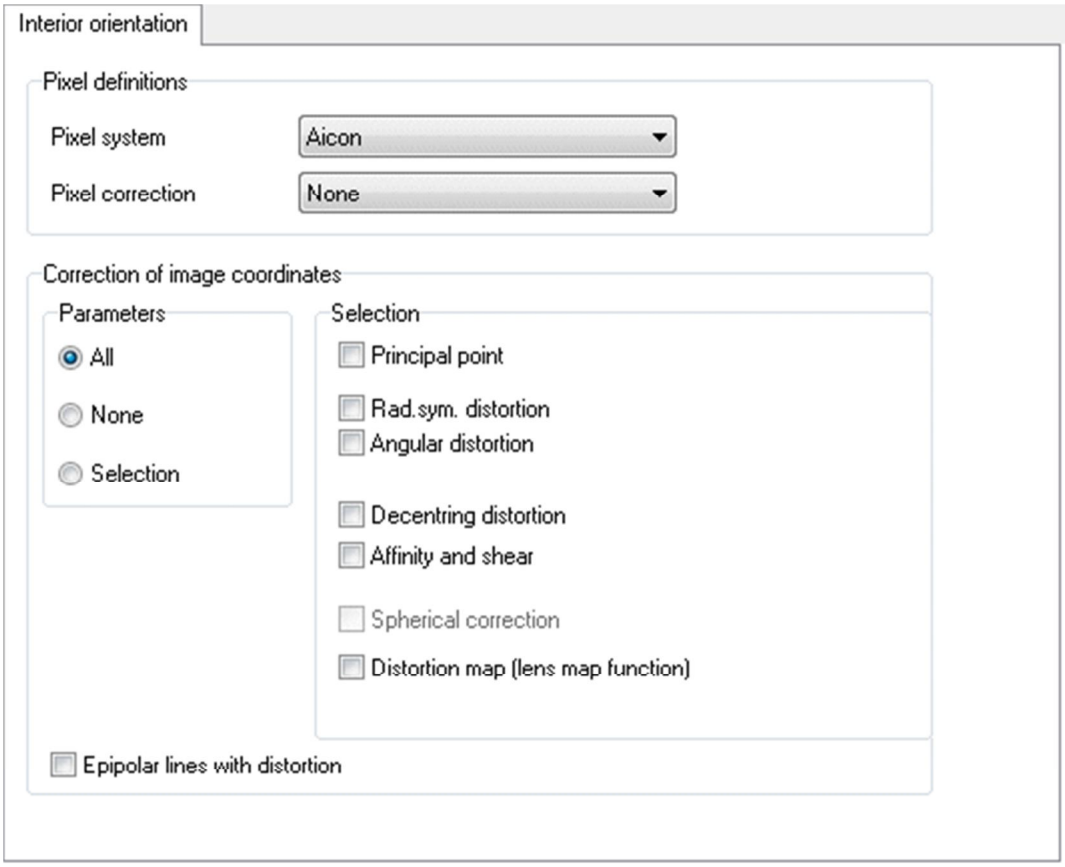


Fig. 29: Options: Compilation / Interior orientation

3.5.14 Orientation

Menu:	Edit → Options → Compilation → Orientation

The page **Orientation** contains options for different image orientation procedures.

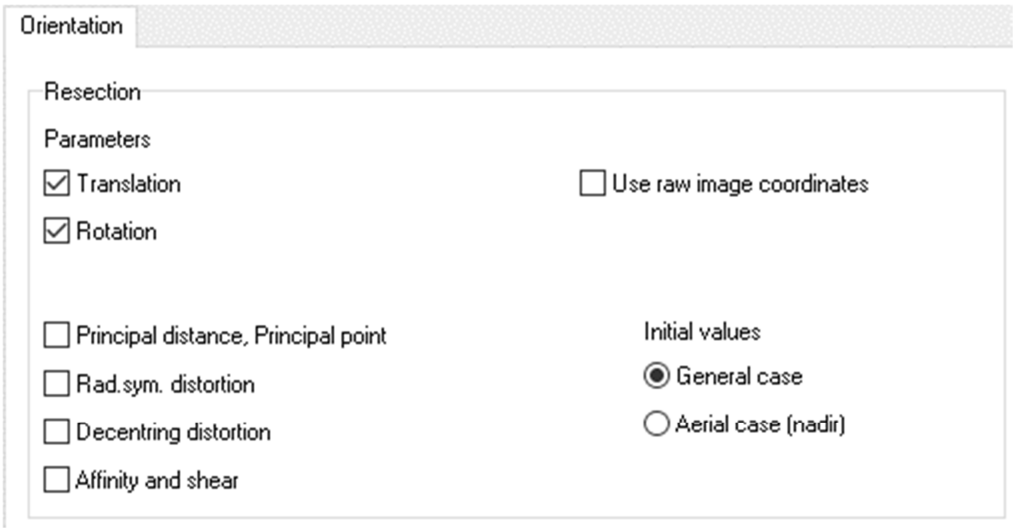


Fig. 30: Options: Compilation / Orientation

Under Resection the following options can be selected:

Translation	Determination of three translation parameters of exterior orientation
Rotation	Determination of the rotation matrix (three angles) of the exterior orientation
Principal distance, principal point	Determination (calibration) of the interior orientation parameters with c, x'_0, y'_0
Rad.sym. distortion	Determination of radial distortion parameters A_1, A_2 (r0 = 0)
Tang.asym. distortion	Determination of the decentring distortion parameters B_1, B_2
Affinity and shear	Determination of affinity and shear C_1, C_2
Use raw image coordinates	The image coordinates used to calculate the individual image orientation are not corrected by principal point position and distortion

Under *Initial vales* the method for calculation of initial values for resection is selected:

General case	Method after S. Kyle (Luhmann et al., Close-Range Photogrammetry and 3D Imaging)
Aerial case (nadir)	Simplified method for vertical (nadir) images.

3.5.15 3D calculation

Menu:	Edit → Options → Compilation → 3D calculation

The page **3D calculation** contains options for different 3D calculation methods.

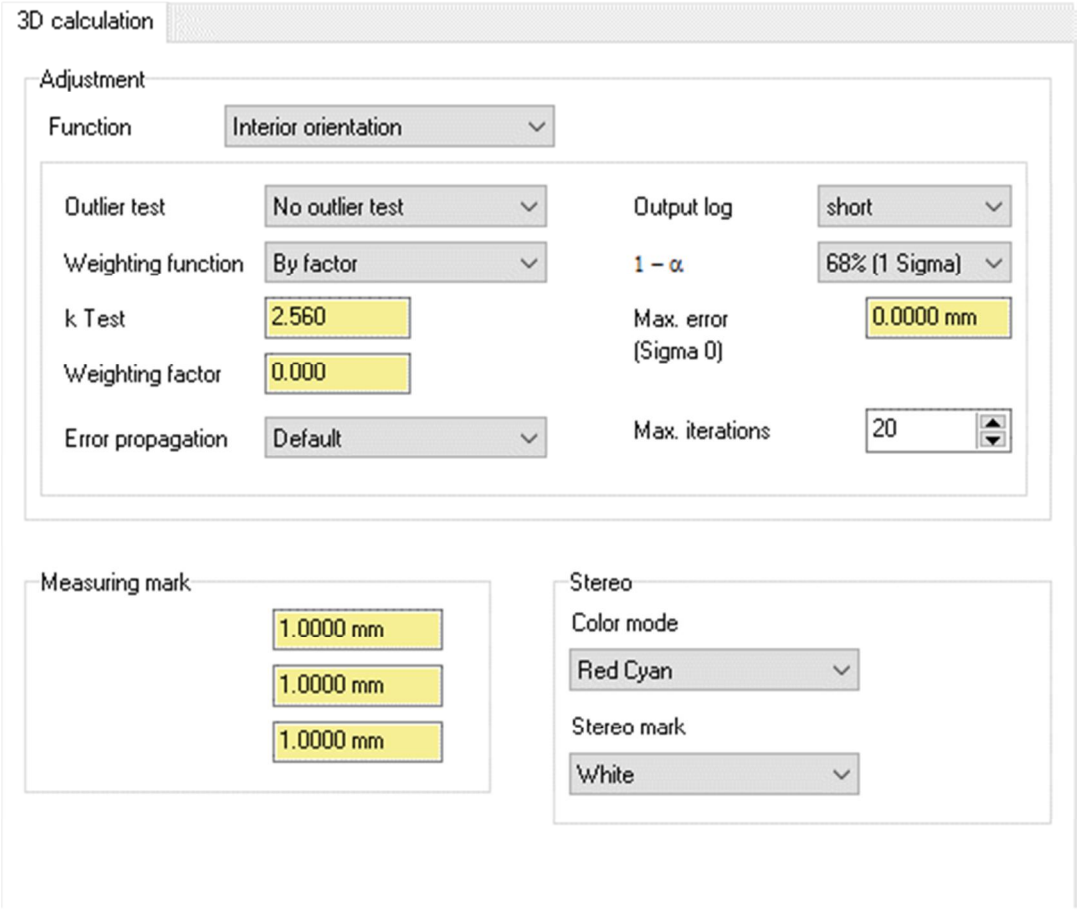


Fig. 31: Options: Compilation / 3D calculation

Under Adjustment control parameters for the selected function are defined:

Interior orientation	Adjustment parameters for the transformation of pixel to image coordinates by means of fiducial marks
Relative orientation	Adjustment parameters for relative orientation
Absolute orientation	Adjustment parameters for absolute orientation or a 3D similarity transformation
Resection	Adjustment parameters for space resection
Intersection	Adjustment parameters for spatial forward intersection
Best-fit plane	Parameters for the calculation of a best-fit plane

For each function individually the following adjustment parameters can be set:

Outlier test	For the elimination of outliers (blunders) the following functions are available: *No outlier test*: no rejection of outliers *Normalized residuals*: Baarda test, an observation is regarded as outlier if the normalized redundancy exceeds the threshold *k test*
Weighting function	Method for treating outliers: *Eliminate*: the outlier is eliminated *By factor*: the observation is down-weighted by factor *Weighting factor* *By function*: not yet implemented
Error propagation	Method for calculation of error ellipses: *Standard*: only standard deviations are calculated *Covariances*: confidence interval from covariance matrix *Eigenvalues*: confidence interval from eigenvalues of covariance matrix
1-α	propabilty of the confidence interval *68% (1 Sigma)* *95% (2 Sigma)* *99% (3 Sigma)*
Max. error	Maximum permissible deviation after the adjustment
Max. iterations	Maximum number of iterations of the adjustment
Output log	Level of detail for a calculation logfile (*none*, *short* or *long*)

Under Measuring mark the following options can be selected:

Delta X, Y, Z	Increment of the movement of a spatial floating mark in object space. The movement can be respectively admitted or suppressed by clicking on the checkbox. The sensitivity of the mouse movement can be set on the page Cursor.

Under Stereo options for displaying and measuring of an anaglyph stereo image can be selected:

Color mode	Color mode of the anaglyph image (e.g. red-green) as described in function **Rectification/Anaglyphs**. Use the button … for adjusting the color weights.
Stereo mark	Color of the stereoscopic floating mark used in function **Measure/Stereo**. *White*: Floating mark is displayed in white color *Black*: Floating mark is displayed in black color *White*: Floating mark is displayed in white color *Color*: Floating mark is displayed in the colors of the selected *color mode*. *Adapted*: Floating mark is displayed in complementary colors of the image content *Individual*: Floating mark is displayed in a user-defined color.

3.5.16 Rectification

Menu:	Edit → Options → Compilation → Rectification

The page **Rectification** contains options for the rectification (ortho projection) of images.

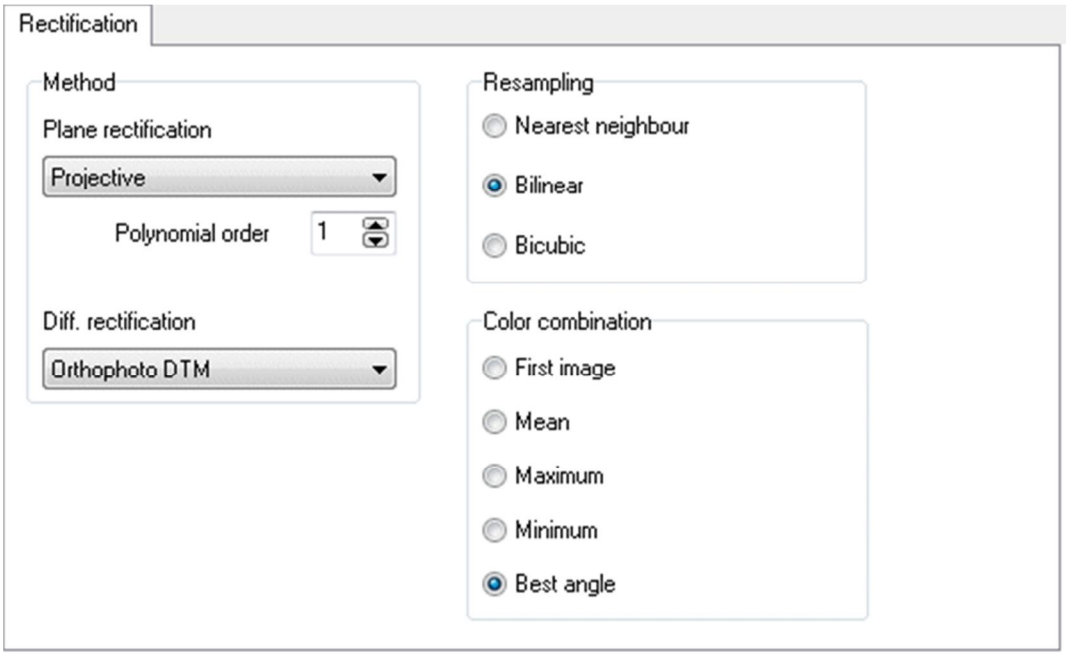


Fig. 32: Options: Compilation / Rectification

Under Method the rectification approach can be selected:

Under *Plane rectification* the function for plane rectification of an image is defined:

Projective	Plane projective transformation: 8 parameters, min. 4 XY control points
Affine	Plane affine transformation: 6 parameters, min. 3 XY control points
Polynomial	Plane polynomial transformation of specified degree n: (n*1)(n*2) parameters, min (n*1)(n*2)/2 XY control points
Bilinear	Bilinear transformation: 8 parameters, 4 XY control points
Helmert	Plane Helmert transformation: 4 parameters, min. 2 XY control points

Under *Diff. rectification* the function for differential rectification of an image under consideration of a 3D surface model is defined:

Orthophoto DTM	Differential rectification on XY ground plane of a DTM
Orthophoto TIN	Differential rectification to XY ground plane of a TIN (triangular meshing)

Under Resampling the following options can be selected for the interpolation of grey values:

Nearest neighbor	Zero order interpolation: worst image quality
Bilinear	Bilinear interpolation 1. order: medium image quality
Bicubic	Bi-cubic interpolation 2. order: best image quality

Under Color combination it is determined which criterion is applied to overlapping images in rectification:

First image	Color value from the first image in the image list
Mean value	Color value as the average of all overlapping images
Maximum	Maximum value of overlapping images
Minimum	Minimum value of overlapping images
Best angle	Color of the image with the best viewing angle
Median	Median value of overlapping images

3.5.17 Simulation

Menu:	Edit → Options → Compilation → Simulation

The page **Simulation** contains options for procedures of the Monte-Carlo simulation.

Under Monte-Carlo simulation the following settings can be made:

Normal distribution	If enabled, a normal distribution is computed with mean 0 and standard deviation 1; otherwise, a rectangular distribution is created.
Max. Sigma	Input of a lower limit that will not exceeded by random variables. Caution: If a value larger than zero is entered, a subsequently calculated standard deviation based of random numbers is estimated too small, hence too optimistic. If zero is set, then all possible random numbers, in extreme case up to infinity, are computed. Only then, the resulting standard deviation is theoretically correct.

Under Noise the optional noise limits according to 1σ are set. Noise limits are only effective if its box is activated and the noise value is >0.

Object coordinates	Uncertainty or measurement noise of object coordinates X, Y, Z.
Image coordinates	Uncertainty or measurement noise of image coordinates x', y'.
Exterior orientation	Uncertainty or measurement noise of exterior orientation parameters.
Camera parameters	Uncertainty or measurement noise of interior orientation parameters.

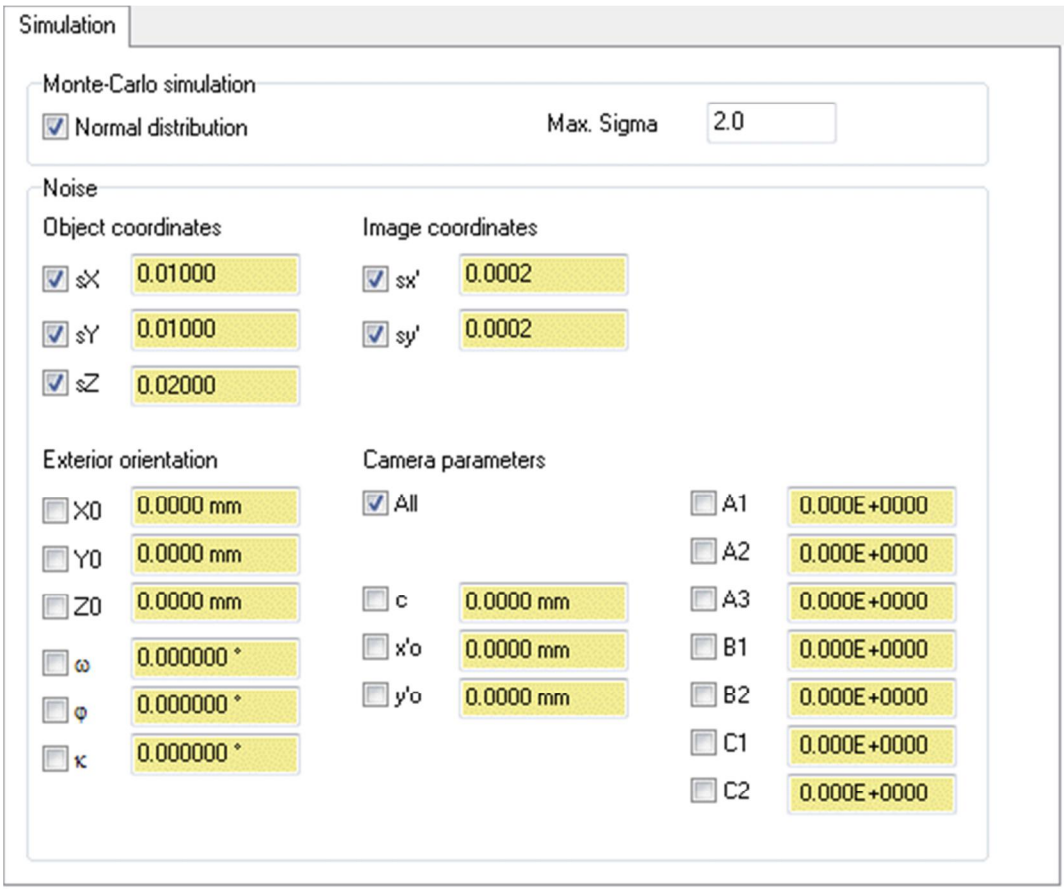


Fig. 33: Options: Compilation / Simulation

3.5.18 3D graphics

Menu:	Edit → Options → Visualization → 3D graphics

The page **3D graphics** contains options for the 3D visualization in VRML or with the integrated 3D viewer.

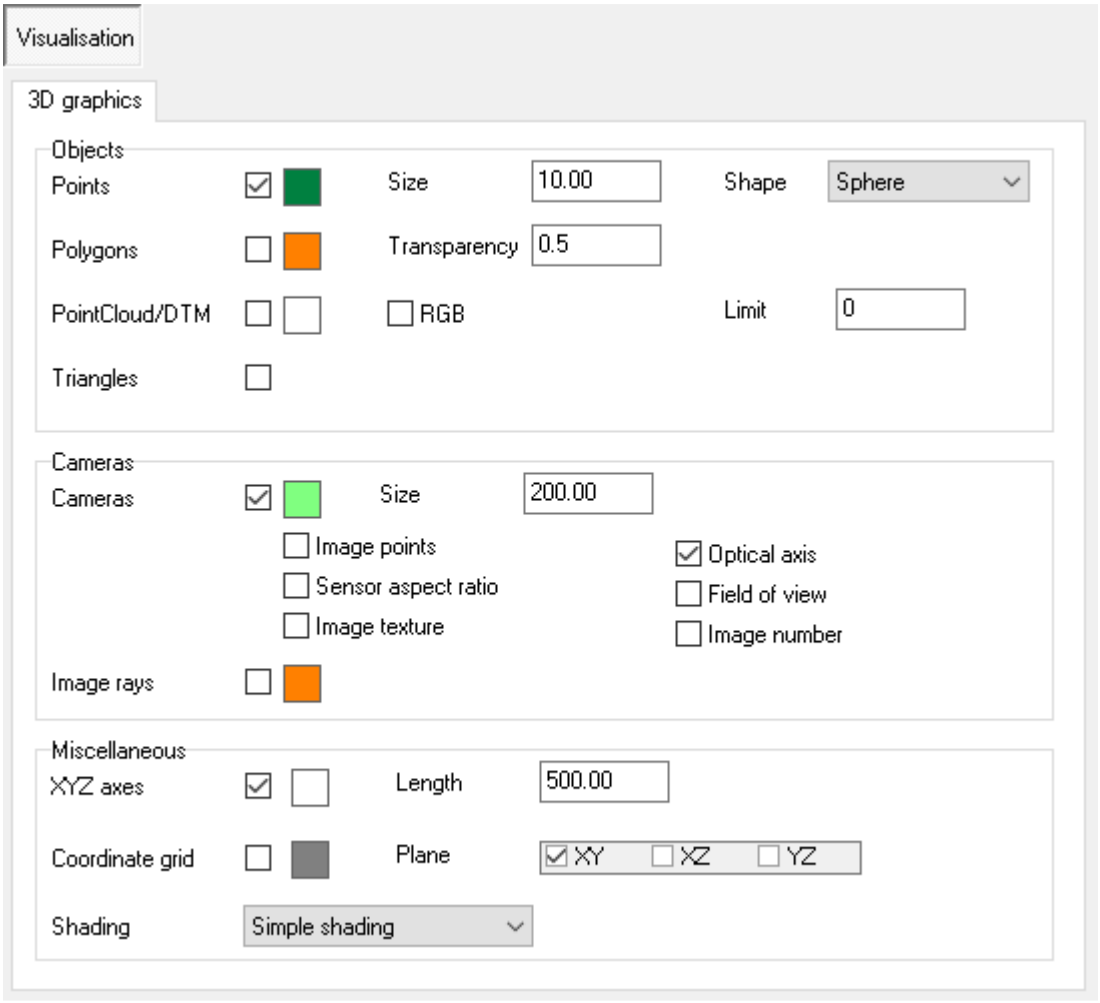


Fig. 34: Options: Visualization / 3D graphics

Under Objects options for displaying object points, polygons, etc. are set:

Points: Display of object points in a desired *Size* [mm] and *Shape*
The optional display of error vectors (standard deviations of points) is defined under **Edit/Options/General/Display**: *Object residuals*.

Point cloud: Display point clouds or DTMs
RGB: the coloured point cloud will be displayed, i.e. each point with its individuall colour or intensity value; otherwise the selected drawing colour will be used.
Limit: maximal number of points to be displayed; 0 means no limit, all points will be drawn.

Polygons: Display polygons in a desired transparency [0...1]

Triangles: Display an existing TIN

Under Cameras options for displaying camera objects are set:

Cameras: Display of cameras in a desired *Size* [mm]. If cameras are displayed, further options are available:
Image points: insertion of image points into the camera object
Sensor aspect ratio: scaling of the camera object according to the sensor format
Optical axis: draws the optical axis (direction) in the length of the XYZ axes

Field of view: draws the borders of the field of view

Image number: displays the image number next to each camera object

Image texture: Superposition of the captured image into the camera object; this option must be set before opening the 3D viewer.

Image rays: Display the image rays from the object point to the image point

Under Miscellaneous more options for 3D visualization can be set.

XYZ axes: Displays the coordinate axes in a desired length [mm]

Coordinate grid: Displays a coordinate grid of the selected plane with the dimensions set under **Edit/Options/General/Graphics**

Shading: Selects the rendering method:

Wire model: representation of polygon lines

Simple shading: rendering with default shading

Lighting: currently not implemented.

3.5.19 Objects

Menu:	Edit → Options → Visualization → Objects

The page **Objects** contains options for selecting 3D objects for the graphical visualization. By clicking on the displayed objects these are enabled and included in the 3D visualization.

Fig. 35: Options: Visualization / Objects

3.5.20 Images

Menu:	Edit → Options → Visualization → Images

The page **Images** contains options for the use of image data for the 3D visualization.

Textures: Insertion of image textures into the surface of the 3D model. To do this, the represented object must have a TIN.

Distance: Definition of a distance criterion for calculating the texture mapping

Angle: Definition of an angle criterion for calculating the texture mapping

Max angle: Maximum permissible angle according to the selected angle criterion

Full path name: The selected images for texture mapping are stored with their full path names in the VRML file.

Interior image area: An image is only used for texture mapping if the associated image ray lies in the central area of the image.

Filling holes: Polygons that could not be assigned to any image (holes) are assigned to the image of the neighboring polygon (Please note: this function requires long computation times).

The specified image list under *Used images* contains all images of the project. Those images which are marked with a check mark are used for texture mapping or for the camera object. The station number is an index indicating whether multiple images belong to the same imaging position, e.g. in the form of a stereo system or a camera triple.

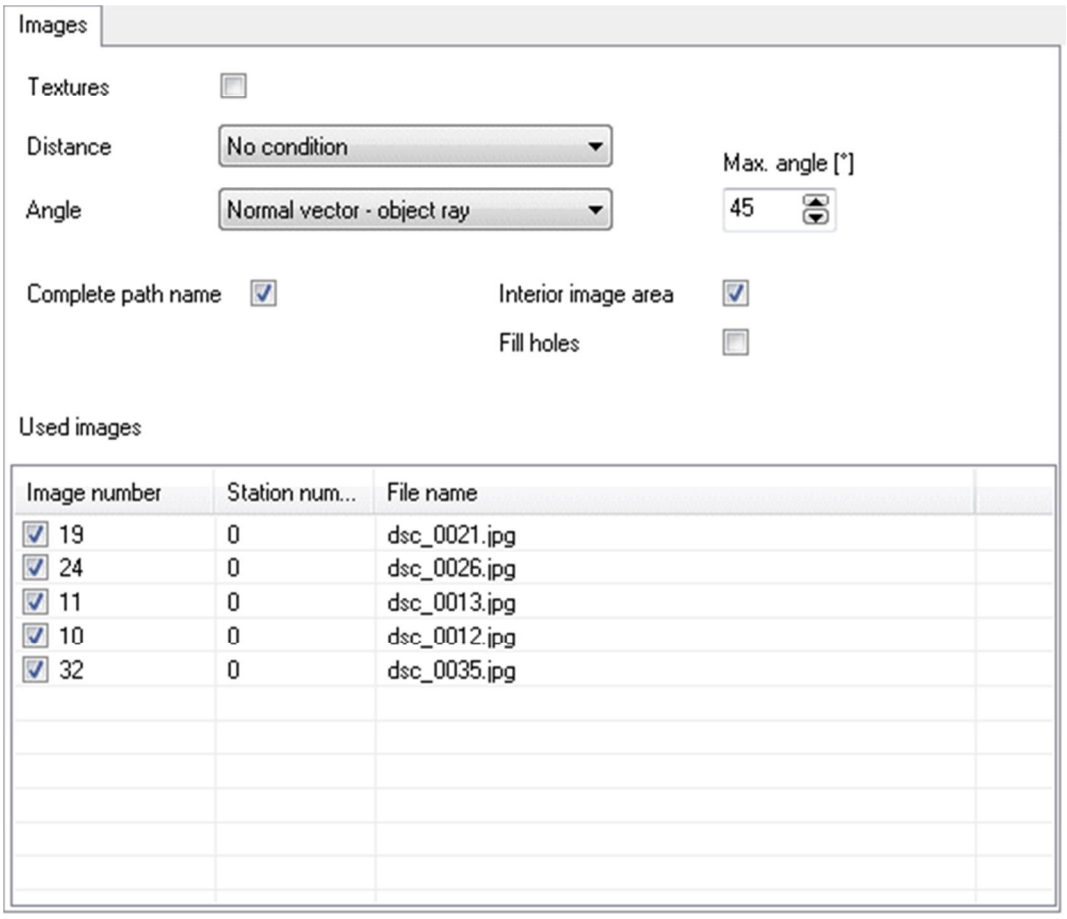


Fig. 36: Options: Visualization / Images

4 Menu Cameras

The **Cameras** menu provides functions for managing and manipulating camera data.

4.1 Camera list

Menu:	Cameras → Camera list
Project tree	Double-click on camera name under Cameras
Precondition:	Project loaded

The function **Camera list** opens a dialog for the management of cameras and camera parameters within the current project. Included are pixel size, physical sensor size, pixel count etc., as well as mathematical parameters for the interior orientation and the image distortion functions.

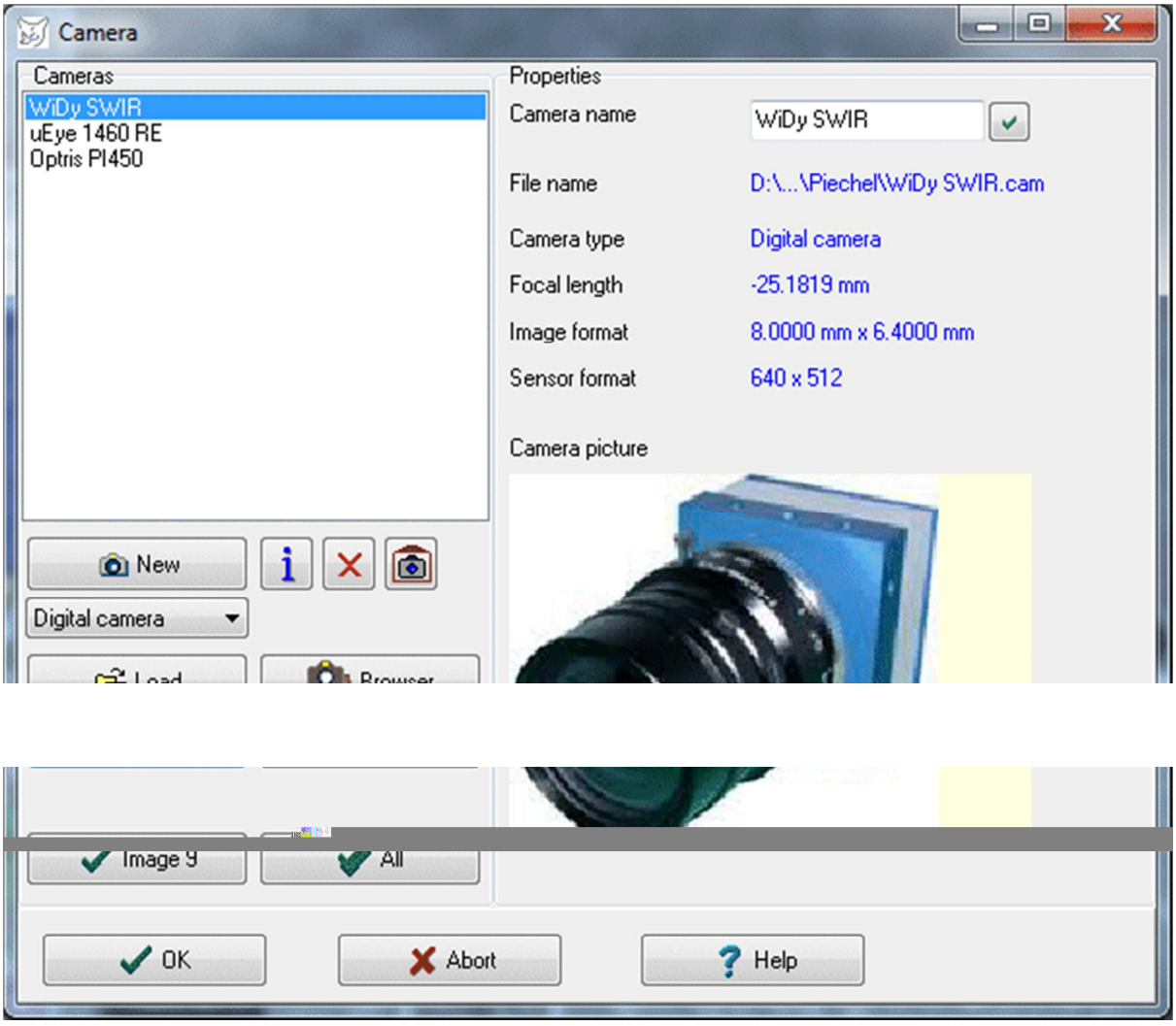


Fig. 37: Camera list

In PhoX camera data is stored in files (*.cam). References to these files are stored in the project file, i.e. without storing the camera data in a camera file these values cannot be loaded after. If a camera has been assigned to a specific image, the image receives a copy of the camera parameters, which are stored along with the image. They will be saved even without a camera file. Changes to the data of a camera are not automatically adjusted to the corresponding images, but must be explicitly associated (see below).

The button New creates an empty camera with the type selected below. Then the dialog for editing camera data opens automatically, to complete the necessary missing entries or to fill the generated camera with meaningful data. Then the new camera object must be saved on file. The following camera types are available on dialog page *Image coordinate system*:

Digital camera:	Normal digital camera, sensor size equal to image size
Fiducials:	Analog camera with fiducial marks, that must be measured under Measure/Interior orientation. The target coordinates of the fiducial marks must be defined in the table.
Reseau:	Analog camera with a reseau instead of fiducial marks. The target coordinates of the reseau points must be defined in the table.
Panorama:	Digital panoramic camera
Aerial image:	Analog metric camera with fiducial marks , that must be measured under **Measure/Interior orientation**. The image format is preset with 230 mm x 230 mm. The target coordinates of the fiducial marks must be defined in the table.
Map:	Scanned map with four corner points (fiducial marks).
Spherical:	Not implemented.
Projective:	Not implemented.

With Load an existing camera files in selectable input formats is loaded. If data in an external format (e.g. *.ior) is imported, these must be stored prior to completion of the project in a PhoX camera file so that it is available again at the next loading of the project. With Library the directory of camera library is opened. Browser opens the Camera browser.

The following input formats are currently supported:

PhoX (*.cam)	Interior orientation of a single camera in PhoX format
AICON 3D-Studio (*.ior)	Interior orientation in AICON 3D-Studio format
Ax.Ori (*.html)	Interior orientation in Ax.Ori format (AXIOS 3D), as included in the output logfile from Ax.Ori
FiBun (*.ior)	Interior orientation in FiBun format (IAPG)
LPS (*.cam)	Exported interior orientation in LPS format
SocetSet (*.cam)	Exported interior orientation in SocetSet format

PhoX (*.pxp)	Interior orientation of an image that is stored in a PhoX project
iWitness (*.txt)	Exported interior orientation in iWitness format
AgiSoft XML (*.xml)	Exported interior orientation in XML format from AgiSoft PhotoScan (File/Export/Export cameras) (parameters are transformed into the metric image coordinate system)
AgiSoft Calibration (*.xml)	Exported calibrated interior orientation from AgiSoft Metashape (Tools/Camera calibration)
Pix4D (*.txt)	Exported interior orientation in text format from Pix4D (possibly a real physical pixel size must be added manually, (parameters are transformed into the metric image coordinate)

Imported camera data from Agisoft or Pix4D must be transformed into a metric image coordinate system using the real physical pixel size of the sensor (see Ch. 4.2.3 Interior orientation).

PhoX format camera files (*.cam) can be added by drag and drop from the file manager (explorer) into the main window of PhoX.

The data of the selected camera are stored with Save. Only camera data that is stored in the internal format, can be assigned to the images.

With the button Image x the selected camera is assigned to the current image. With All the selected camera is assigned to all existing images. In both cases, existing parameters of interior orientation of the image are overwritten.

The button  opens the dialog for editing the camera parameters. This function is also directly available with the menu function **Cameras/Parameters**. If camera parameters have been changed, the camera name in the list is marked with *.

With  the selected camera is assigned to the camera library. During this process, it generates a new file name composed from camera name, focal length, and number of pixels.

With  the selected camera is permanently removed from the camera list.

Under *Properties* the most important parameters of the currently selected camera are displayed. Only here, the camera name can be changed, after the input will be confirmed with  .

4.2 Parameters

Menu:	Cameras → Parameters
Precondition:	Existing camera

In the window **Parameters** the parameters belonging to a selected camera can be edited. The window can be closed with OK when all the necessary entries have been made correctly. Incorrect input fields are highlighted.

4.2.1 Description

The page **Description** allows the setting of an arbitrary description text for the camera.

Camera name: Displays the camera name. It can be changed only in the menu function **Cameras/Camera list**.

File: Displays the file name under which the camera is stored.

Description: Input of any text for a short description of the camera.

Camera picture: Displays a picture of the camera. With the button Load picture any image file can be loaded. Its file name is stored with the camera file. The image is displayed with up to 150 x 100 pixels, hence the imported image can be reduced to that size.

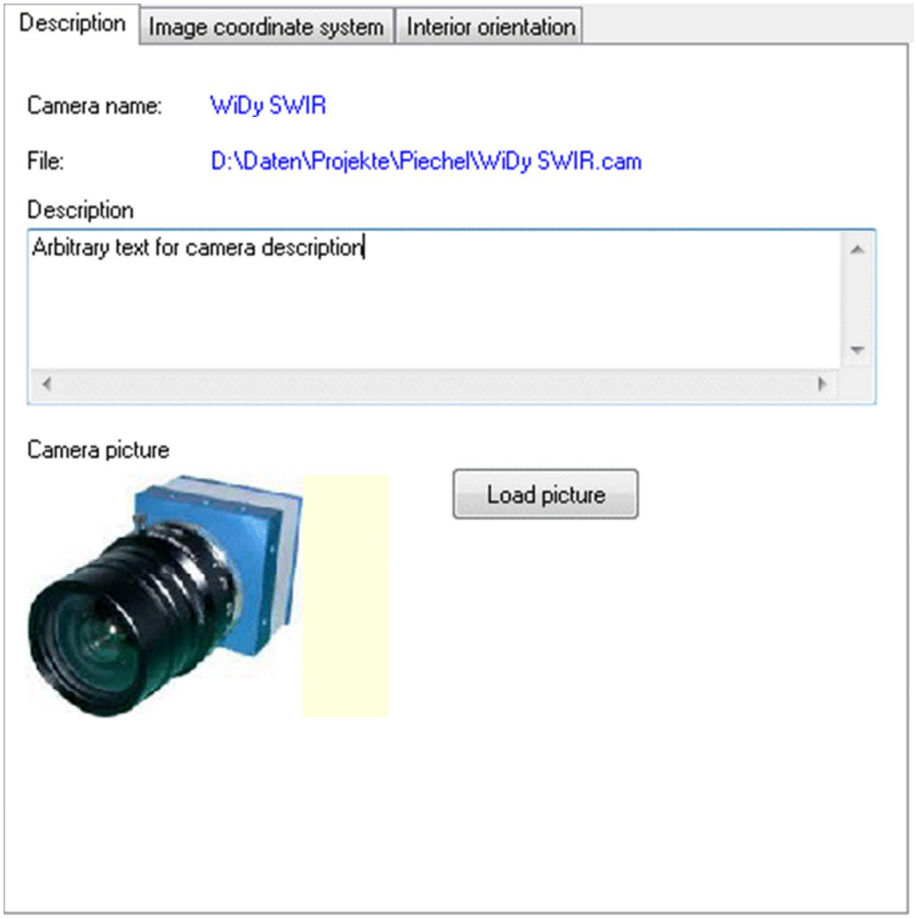


Fig. 38: Camera parameters: Description

4.2.2 Image coordinate system

The page **Image coordinate system** describes the dimensions of the sensor (film), and the transformation type between the pixel coordinates of the stored image and the camera coordinate system. Coordinates of fiducial marks can be specified only if a suitable camera type has been selected.

Camera type: This determines which type of camera was used to acquire the images. Camera type and transformation must match (see below). The available camera types are explained under **Cameras/Camera list**. The button  selects the default *Transformation* according to the selected camera type

Transformation: Defines which transformation of pixel coordinates into the camera coordinate system is used in function Interior orientation. Following selections are available:
digital [mm]: pixel coordinates are transformed to the corner points of the image format in [mm] (Default)
digital [pixel]: no transformation applied, image coordinates are measured in the unit [pixels].
6-par. affine: measured pixel coordinates and given coordinates of camera reference points (fiducial marks, image corners) are transformed by affine transformation.
4-par. Helmert: measured pixel coordinates and given coordinates of camera reference points (fiducial marks, image corners) are transformed by a 4-parameter Helmert transformation (similarity transformation).
Panorama: transformation of the image coordinates of a panoramic image
spherical: transformation of the image coordinates of a spherical image
Zoom: not implemented
projective: not implemented

Image format: Coordinates of the upper left corner and the lower right corner of the image format. By default, the system should be defined so that the origin lies in the middle of the image. With the button  the *image format* is calculated from given data for columns, *rows* and *pixel sizes.* The switch  computes the (optional) coordinates of fiducial marks from the image format.

Sensor format: Number of *columns* (x) and *rows* (y) of the camera sensor. This information must match the actual size of the digital images. With the button  these values be can taken from the currently selected image. With the button the corresponding *pixel sizes* are calculated from given data of the image format and the *columns* and *rows*.

Pixel size x, y: Size of a sensor element in x and y direction. With the button  the corresponding *columns* and *rows* are calculated from data of the image format and the pixel sizes.

With the button sensor and image format data can be read from a different camera file. With the button the values of an existing camera can be loaded. Here, the data of interior orientation is not imported.

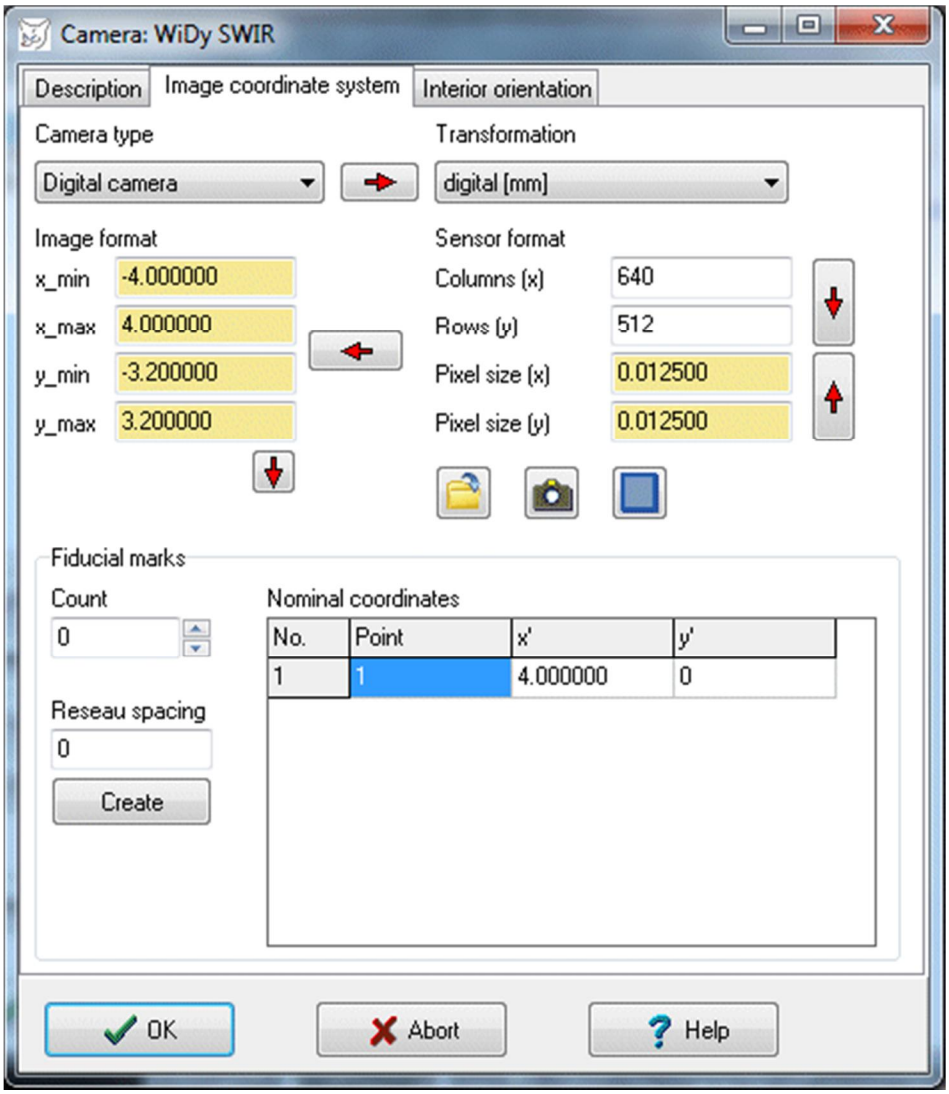


Fig. 39: Camera parameters: image coordinate system

Under Fiducial marks settings about configuration and nominal coordinates of reference points of the camera can be defined.

Count: Number of fiducial marks or reseau points of a camera. The value must be null for camera type *digital camera* and transformation type *digital*.

Nominal coordinates: Table with coordinates of reference points in the camera coordinate system in the format

```
Point number     x'     y'
```

defined according to the above *count*. The point numbers must be unique.

Reseau spacing: The distance [mm] of reseau points to be created with Create

4.2.3 Interior orientation

The page **Interior orientation** contains the parameters of the standard camera model with

Calibration model:	Selection of the mathematical model for the description of interior orientation. The input fields are displayed depending on the choice. *Default*: interior orientation with distortion parameter A1 to A7 and optional r0 *Angle*: angle-depending distortion model with F1 to F5 *Brown*: Brown's parameters K1 to K3 *Spherical*: Spherical imaging parameters for fisheye lenses *Lens map*: distortion parameters are interpolated from a table of distortion values The other models are not yet implemented.
Principal distance c:	This value must be negative in image coordinate units, default [mm]
Principal point x'_o, y'_o:	Coordinates of the principal point position in image units, default [mm]
A1 to A7:	Coefficients of radial-symmetric distortion (optionally F or K parameters)
r0:	Position of the second zero crossing of the balanced distortion function in image coordinate units, default [mm]
K0:	Polynomial coefficient K0 of the linear component of radial distortion
B1, B2:	Coefficients of tangential and asymmetric (decentring) distortion
C1, C2:	Coefficients for affinity and shear
Distortion map:	Possibility to read a table of the distortion values (lens map function) from file for calibration model *Lens Map*
f	Reference focal length of the distortion table (must be non-zero) for calibration model *Lens Map*

With the button  the calibration data is taken from the currently selected image object. With the button  the values can be read from an existing camera, while the data of the image coordinate system are not imported. With CV the parameters of interior orientation in pixel coordinate system (e.g. from computer vision) are transformed into metric parameters according to the following table:

Parameter	metric	pixel-based	Transformation	Unit
Principal distance	c	f	$c = -f \cdot \Delta s'$	mm
Principal point	x'_0 y'_0	u_0 v_0	$x'_0 = u_0 \cdot \Delta s'$ $y'_0 = -v_0 \cdot \Delta s'$	mm
Radial-symmetric distortion	A_1	K_1	$A_1 = K_1 / c^2$	1/mm^{-2}
	A_2	K_2	$A_2 = K_2 / c^4$	1/mm^{-4}
	A_3	K_4	$A_3 = K_3 / c^6$	1/mm^{-6}
Decentring distortion	B_1	P_1	$B_1 = P_1 / c$	1/mm
	B_2	P_2	$B_2 = -P_2 / c$	1/mm
Affinity and shear	C_1	B_1	$C_1 = B_1 / f$	
	C_2	B_2	$C_2 = -B_2 / f$	

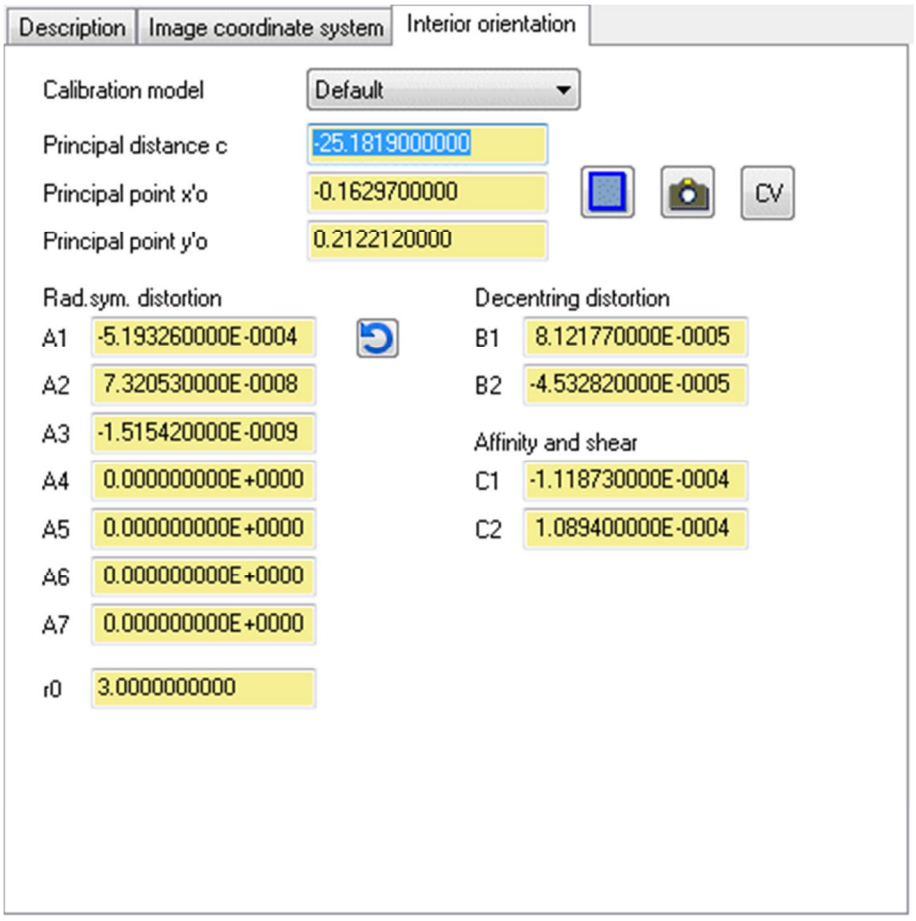


Fig. 40: Camera data for the interior orientation

At least the value of the principal distance c must be defined on this page, all other sizes can be set to null.

4.3 Camera table

Menu:	Cameras→ Camera table
Precondition:	Project loaded

In the window **Camera table** all existing cameras are listed with their camera data. The data cannot be edited here.

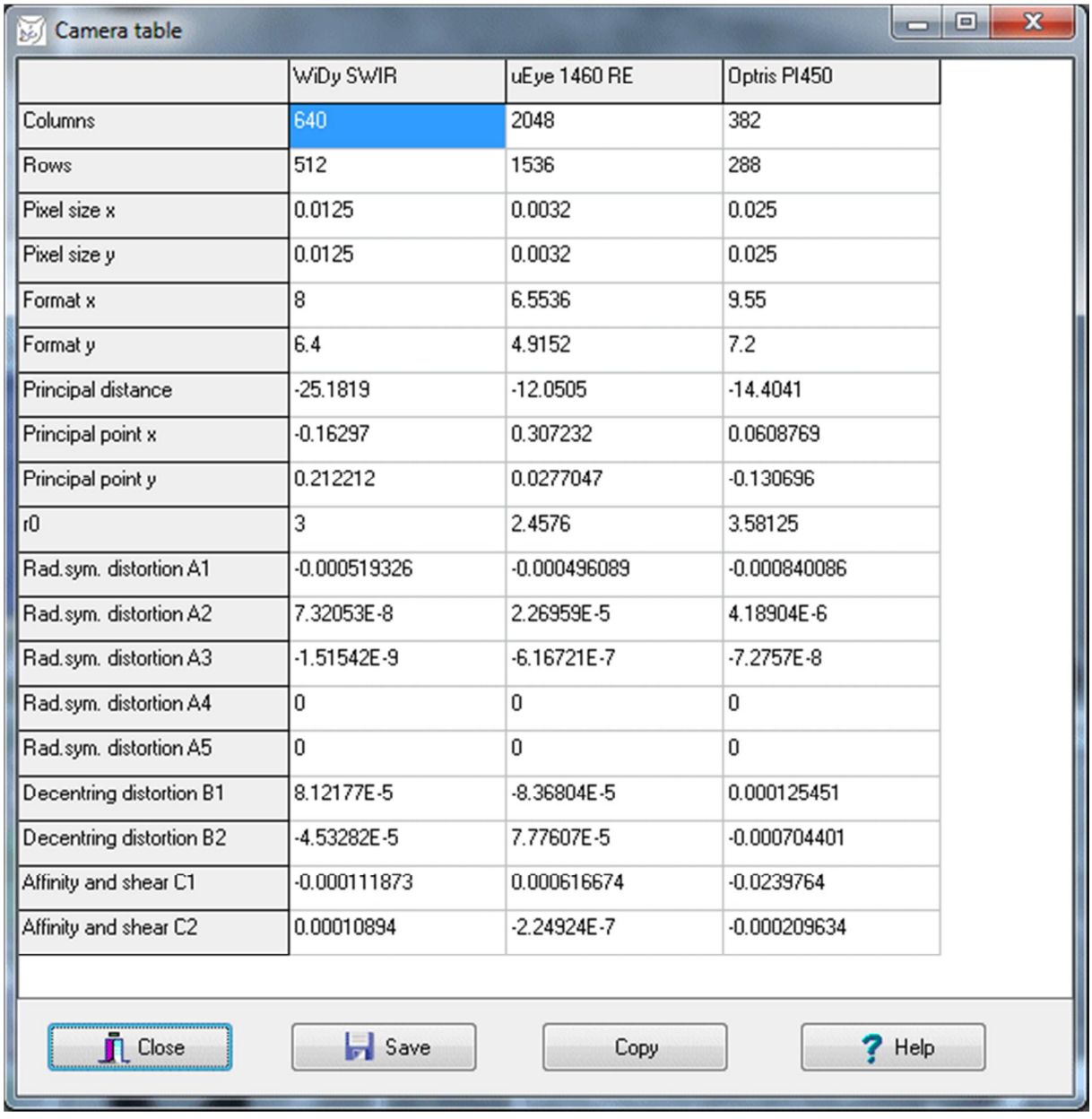


Fig. 41: Camera table

The button Save allows to store the table in an Excel compatible text file. With the button Copy the table is copied to the Windows clipboard.

4.4 Camera browser

Menu	Cameras → Camera browser
Project tree	Double-click on Cameras
Precondition:	Project loaded

In the window **Camera browser** the entire directory tree can be searched for camera files. The files in a selected directory are represented in the list view. Some related camera data is displayed when a camera file is selected in the list.

Currently the following camera formats are supported:
- PhoX (*.cam)
- AICON 3D-Studio, DPA-Win (*.ior)

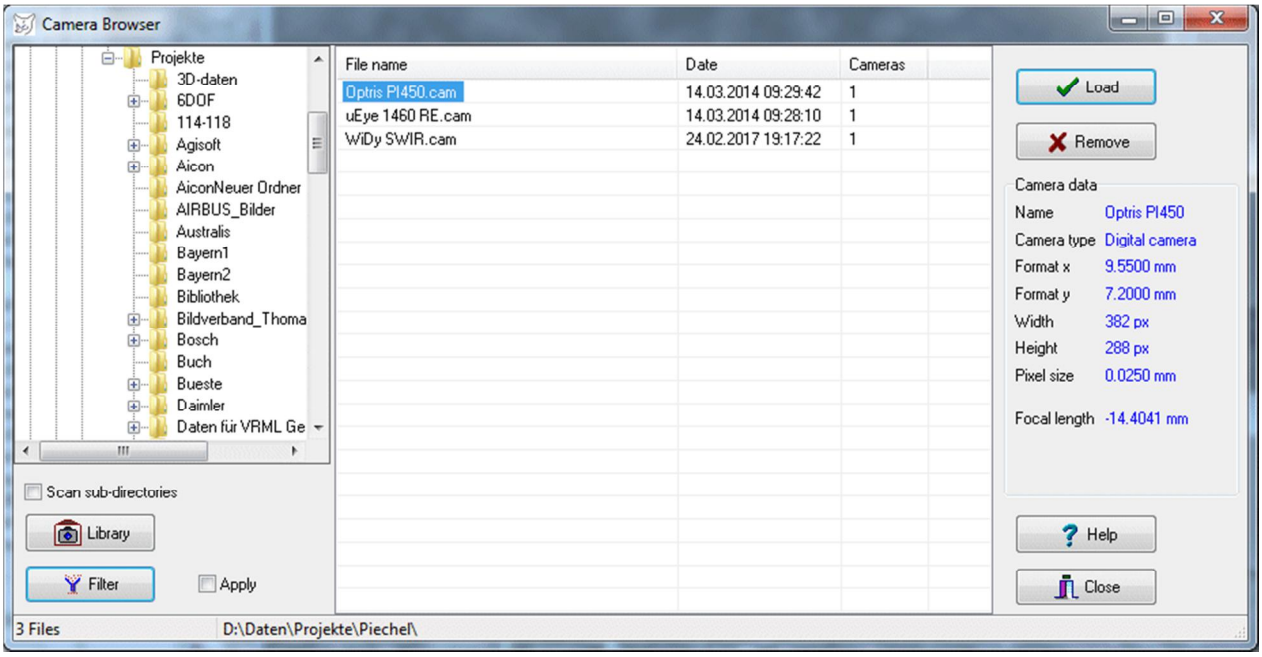


Fig. 42: Camera browser

If the option *Scan subdirectories* is enabled, all subdirectories are searched for corresponding files starting from the currently selected directory. This can lead to longer processing times. The button Library selects the directory of the camera library directly. With the button Filter specific selection criteria for camera files can be defined (see **Project/Preview project**) and applied when the *Apply* option is enabled.

With the button Load or by double-clicking a list entry the selected camera files will be loaded and the window is closed. With Remove all selected camera files will be deleted after confirmation.

4.5 Optics

Menu:	Cameras → Optics
Precondition:	Project loaded

With the function **Optics** a window is displayed where the optical parameters of image acquisition can be calculated and displayed.

Under Basic settings the current image, the current camera and the current 3D object can be selected. With EXIF data of the EXIF header of the current image is displayed with existing image and optical parameters, if the image file provides this information.

Under Lens the following parameters of the lens can be set:

Focal length: Input of the focal length. After entering the values for *Aperture*, *Focus distance*, *Circle of confusion* in the image as well as the distance to the *Closest point* and the *Farest point*, the required *Focal length* for sufficient focus is calculated.

Aperture: Input of the aperture (f-stop number). After entering the values for the *Focus distance*, *Focal length*, size of the acceptable *Circle of confusion* in the image as well as the distance to the *Closest point* and the *Farest point*, the required *Aperture* for sufficient focus is calculated.

Image circle: Not implemented.

Under Focus calculations for the depth of field and its influences are made. *Calculation* determines which values depending on the other parameters will be calculated. Following options are available:

Depth of field: After entering the values for *Focal length*, *Aperture*, *Focus distance* and size of the acceptable *Circle of confusion* in the image, the distances to the *Closest point* and the *Farest point* are calculated which are sufficiently in focus. The *Depth of field* is the difference of these two distances.

Aperture: After entering the values for the *Focus distance*, *Focal length*, size of the acceptable *Circle of confusion* in the image as well as the distances to the *Closest point* and the *Farest point*, the required *Aperture* is calculated.

Focal length: After entering the values for *Aperture*, *Focus distance*, *Circle of confusion* in the image as well as the distance to the *Closest point* and the *Farest point*, the necessary *Focal length* is calculated.

Focus distance: After entering the values for *Aperture*, *Focal length*, *Circle of confusion* in the image as well as the distance to the *Closest point* and the *Farest point*, the required *Focus distance* is calculated.

Circle of confusion: After entering the values for *Aperture*, *Focal length*, *Focus distance* as well as distance to the *Closest point* and the *Farest point,* the resulting size of the *Circle of confusion* is calculated.

The respective input and result fields are indicated by the appropriate symbols. The following parameters are calculated according to the above settings:

Image distance: After entering the values for *Focal length* and *Focus distance*, the resulting *Image distance* is calculated.

Closest point: Minimum object distance from where the image is in focus.

Farest point: Largest object distance to where image is in focus (can be infinite).

Depth of field: The depth of field is the difference of the distances between *Closest point* and *Farest point*.

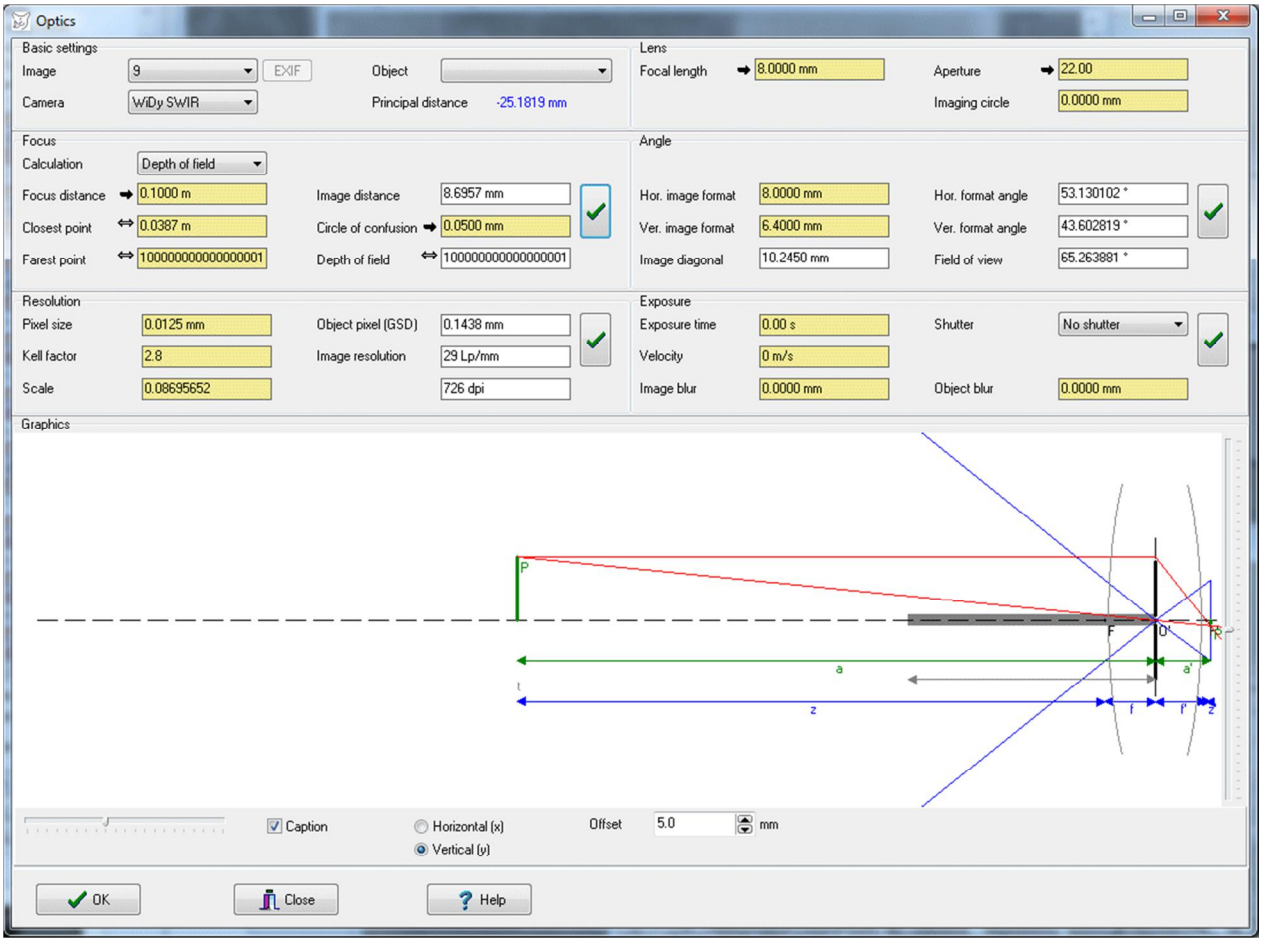


Fig. 43: Window to calculate lens parameters

Under Angle the camera's format angle depending on sensor size and focal length is calculated:

Hor. image format: Input of the horizontal (x) image format in mm. When selecting a camera or an image, their size is entered here automatically.

Ver. image format: Input of the vertical (y) image format in mm. When selecting a camera or an image, their size is entered here automatically.

Image diagonal: Size of the resulting image diagonal.

Hor. format angle: Angle of the horizontal (x) format as a function of horizontal image format and *focal length*.

Ver. format angle: Size of the vertical (y) format angle as a function of vertical screen format and *focal length*.

Field of view: Angle as a function of *image diagonal* and *focal length*.

Under Resolution parameters for resolution in image and object space are calculated:

Pixel size:	Input of the physical pixel size of the image in mm. When selecting a camera or an image, their size is entered here automatically.
Kell factor:	Factor indicating how many pixels are required for sufficient scanning of an object. After Shannon's sampling theorem it is the factor 2, while the so-called Kell factor has a value of 2.8, i.e. the object must be sampled 2.8 times more dense to resolve an object detail.
Scale:	Resulting magnification ratio of *image distance* / *focus distance*.
Object pixel (GSD):	Size of the resulting pixel size in object space (ground sample distance) as a function of pixel size and magnification (*focus distance* / *image distance*).
Image resolution:	Resulting image resolution (= *pixel size* x *Kell factor*) in lp/mm or dpi.

Under Exposure parameters for the shutter or exposure time are set:

Exposure time:	Exposure time in seconds.
Shutter:	Choose of the type of shutter in the lens or the sensor: *No shutter* Focal-plane shutter horizontal Focal-plane shutter vertical
Velocity:	Speed of the camera relative to the object (perpendicular to the imaging direction)
Image blur:	Resulting motion blur in the image
Object blur:	Resulting motion blur in object space

Under Graphics a scaled drawing of the fundamental optical design is displayed. Sensor format, focal length, aperture and object distance match the above given values. The following items are displayed:

Sensor format:	Size of the vertical image format (y direction)
Format angle:	Vertical format angle
Image distance a':	Distance from the projection center O' to the focused image plane
Focus distance a:	Distance of the object point P from the projection center (object distance)
z, z':	Focus-related object and image distances
Focal lengths f, f':	Object- or image-sided focal length
Depth of field t:	Depth of field in object space

The magnification factor of the graphic can be changed using the slider. Optionally, a dimensioning of the distances can appear with *Caption*. *Offset* defines the distance of the object point to the optical axis in millimeters.

Entered or modified data are stored after confirmation with OK.

5 Menu Images

The **Images** menu provides functions for managing and editing images.

5.1 Browser

Menu:	Images → Browser
Precondition:	Project loaded

The function **Browser** opens a file explorer, in which one or more image files can be loaded. While the window is opened, it can cause delays because the entire directory tree is read.

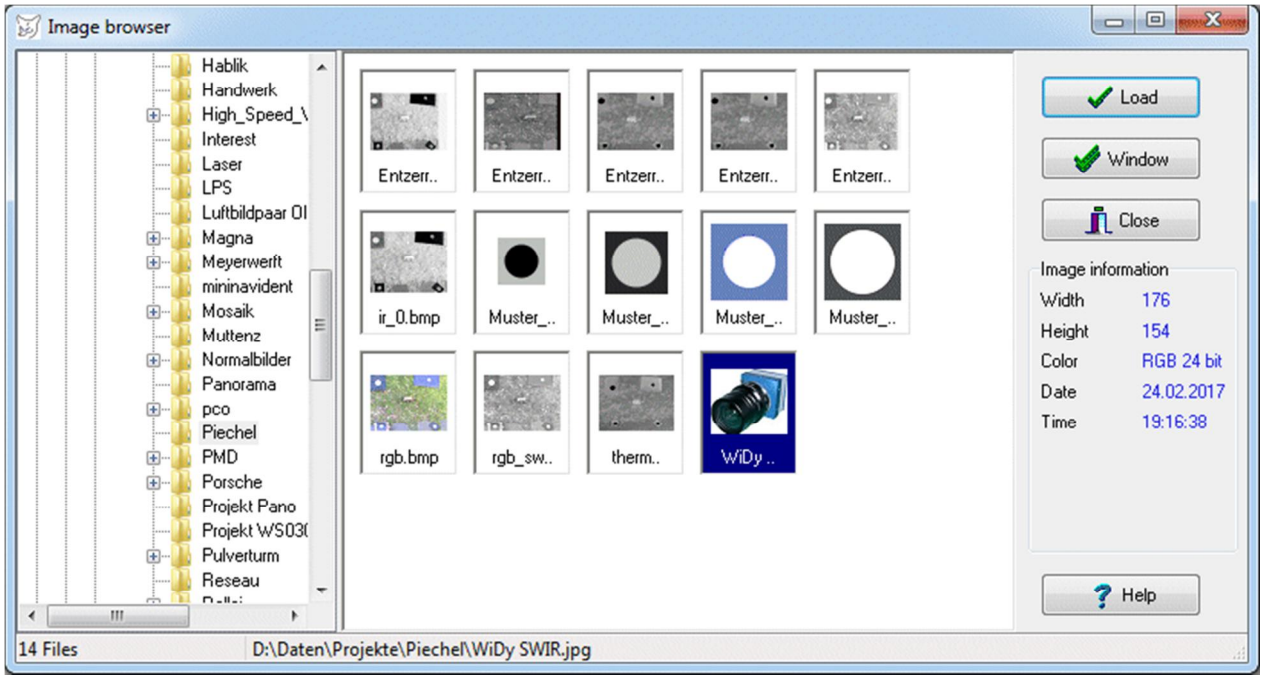


Fig. 44: Image browser

With Load the selected images are transferred into the project. The button Window loads all selected files as well but also creates related image windows.

5.2 Load image

Menu:	Images → Load image
Button:	
Project tree:	Double-click on Images
Precondition:	Project loaded

The function **Load image** opens a dialog in which one or more image files can be loaded.

Image files can also be opened by drag and drop from the file manager (explorer) into the main window of PhoX. Alternatively, the function in the popup menu of the project tree can be invoked, if the node Images has been tagged.

After loading, the image is listed as an image object in the Project tree. To display, it must be marked and loaded into the Image window. Alternatively, the image object can be displayed by drag & drop into the main window of PhoX. If the option *Window* > *Automatic* has been activated under **Edit/Options/General/Program**, loaded image files are immediately displayed in an image window.

5.3 Save image

Menu:	Images→ Save image
Precondition:	Existing image with bitmap

The function **Save image** is used to save the current image to file. The output format (JPG, BMP, TIFF, etc.) can be selected arbitrarily. Depending on the image format more options in the file dialog are available.

5.4 Save all images

Menu:	Images → Save all images
Precondition:	Existing image with bitmap

The function **Save all images** is used to save all modified image data (bitmaps). The output format is identical to that of the original image or the .bmp format, if synthetic images have been generated. The output directory (file folder) is identical to the original image or the current directory and cannot be changed at present. The file name to be created can be set in an additional dialog, where any character string can be inserted before or after the name of the image. It has to be ensured that the composite strings result in a Windows compliant file name.

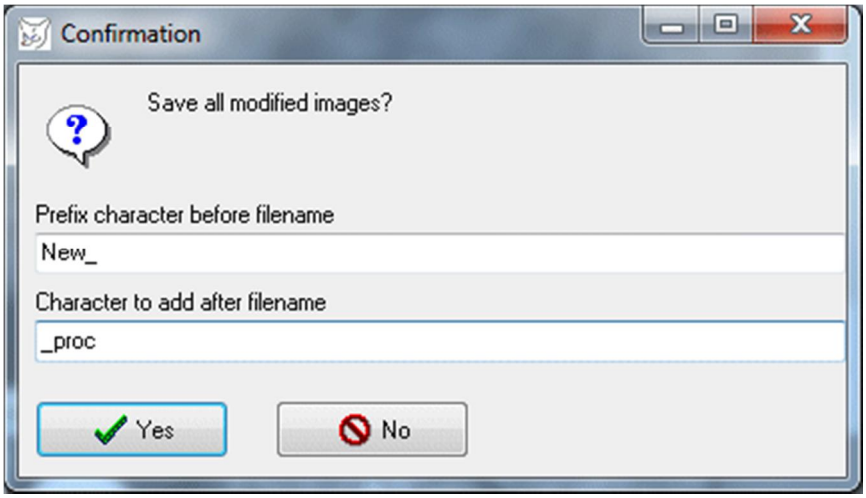


Fig. 45: Dialog to set the output file name

In this example, the file name is made up of the first string, the current name of the image and the second string. After confirmation with Yes, all new or changed bitmaps are automatically saved.

5.5 Filter

Menu:	Images → Filter
Precondition:	Existing image object

The function **Filter** opens a dialog for the filtering of image objects. Filter functions are explained under **Objects/Filter** in more detail.

5.6 Create images

Menu:	Images → Create images
Precondition:	Loaded project

The function **Create images** opens a dialog to create new image objects.

Under Single image images with equal orientation values are generated.

Number of new images: Number of images to be generated

Image numbers from: Image number of the first generated image, next images will be consecutively numbered.

Based on image: Image number of the image that is used as the basis for generating new images. The new images have the same parameters (size, interior orientation, etc.) as the template.

With Create the images are created.

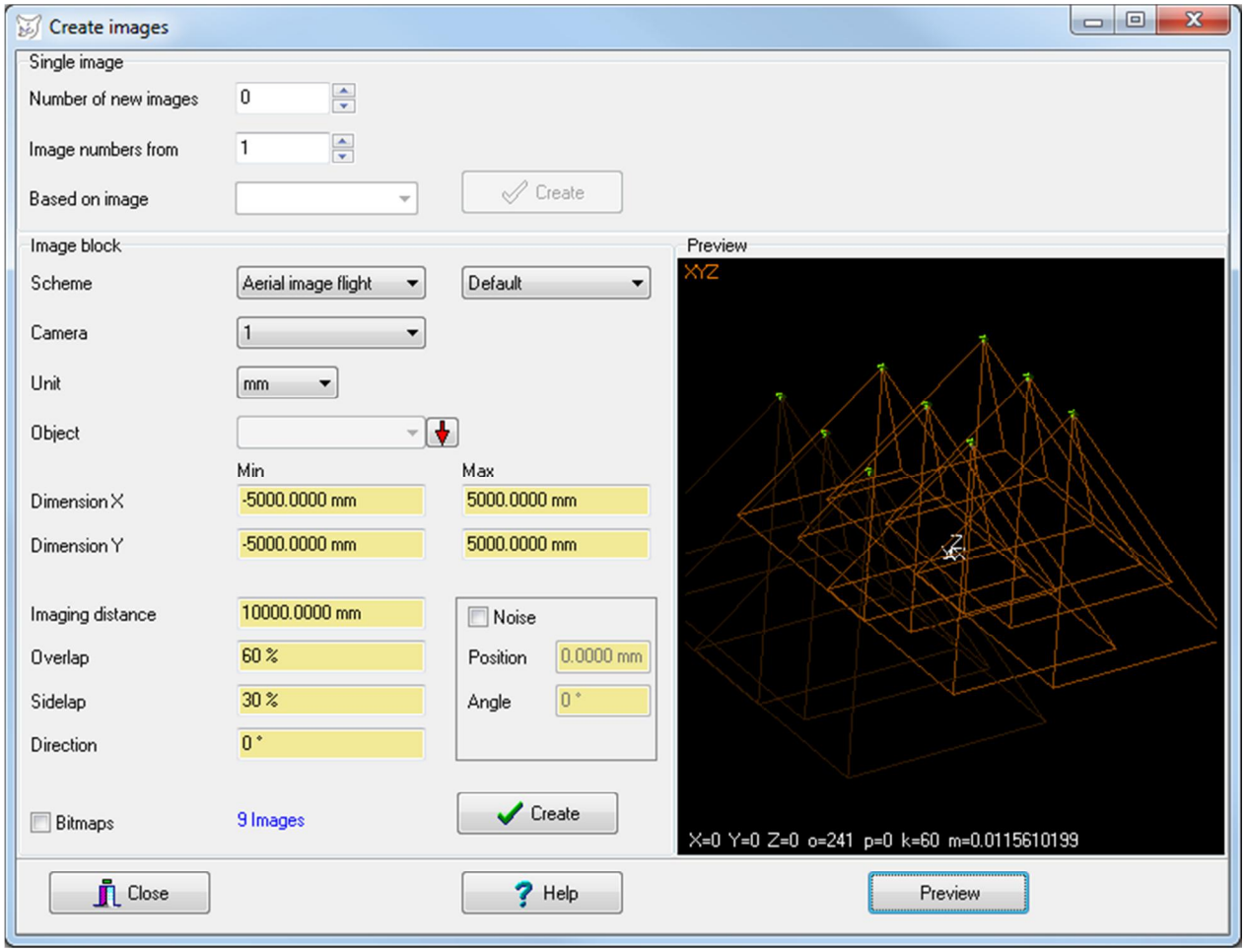


Fig. 46: Dialog to create new image objects

Under Image block images are generated with different exterior orientation values according to a specified imaging configuration. The following configurations are available:

Scheme	Variation	Remarks
Aerial image flight	Default	Standard flight scheme with nadir looking camera
	Oblique	Standard flight scheme 1 nadir and 4 with oblique cameras
Close range	Sphere	Images arranged in a semi or full sphere around the origin
	All-around	Images arranged in a ring around the origin
	Test field calibration 8	8 images are arranged over the object, 4 rotated nadir images and 4 tilted images from all side
Miscellaneous	Single image	1 nadir image is created
	Stereo model	1 stereo pair is created
	Object points	Perspective centers are given by the object points of the selected *Object*

Scheme: Basic imaging arrangement to vary the exterior orientations (see below)

Camera: Selection of the camera; its format and interior orientation is associated with the images. No image configurations can be created without a selected camera.

Unit: Unit for the input of dimensional values

Object: Selection of an object to be used for the scheme *Object points*.

Dimension X,Y Dimension of the recorded area Xmin, Xmax, Ymin, Ymax

Imaging distance: Distance of the images of the object in the Z direction, e.g. altitude

Radius: Radius of a semi-sphere or spherical configuration

Base length Length of the base between two stereo images

Overlap: Percentage longitudinal overlap (in X direction) p

Sidelap: Percentage of side overlapping (in the Y direction) q

Horizontal angle: Horizontal angle between adjacent images or other angle input (see below)

Vertical angle: Vertical angle between adjacent images or other angle input (see below)

Angle: Oblique angle (vertical or nadir recording is equivalent to 0°, see below)

Following recording arrangements are available under the scheme *Aerial image flight*:

Default: Regular image configuration using the entered data for the dimensions of the area, the *overlap*, *sidelap* and *imaging distance* (height). The flight direction is defined under *Direction* (0° = direction in X).

Oblique: Regular image configuration as with *Default*, but with four additional oblique images with the specified *Angle* (must be non-zero)

Following recording arrangements are available under the scheme *Close range*:

Sphere: Images are distributed like a sphere above the XY-plane. A number of new images with the angular difference between neighbouring images entered in the *Horizontal angle* is positioned on the equator of the sphere with the defined *Radius*. Then more images are arranged evenly up to the pole. With *Vertical angle* = 90°a semi-sphere, with 180°a full sphere is created.

All-round: Creates a ring-shaped image arrangement with *Radius*. The number of new images results from the angle difference entered as *Horizontal angle* between adjacent

images. With *Vertical angle* the vertical recording direction (0°= horizontal direction) is determined.

Test field calibration 8: Eight pictures in a typical configuration of recording a test field for camera calibration (4 rotated vertical images from the top and 4 tilted images from the sides)

Following recording arrangements under the scheme *Miscellaneous*:

Single image: Creates a single image.

Stereo model: Creates two images in the distance of the *Base length* with the convergence angle entered φ (0°= normal case of stereo photogrammetry)

Object points: Perspective centers are given by the stored points of the selected *Object* with the optical axis directed to the coordinate origin

if non-null values are entered under *Noise*, randomly distributed changes of the exterior orientation of images in location and angle are applied.

The number of expected images based on the entered values is displayed. With Preview the calculated image configuration is displayed in a 3D viewer. With Create the images are created after confirmation and, if necessary, empty Bitmaps are created for each image.

5.7 Image assignments

Menu:	Images → Image assignments
Precondition:	Existing image object

The function **Image assignments** allows the assignment of image and station number, camera and image file to selected images.

Image number: Integer number of the image, must be unique for each image in the entire project (double image numbers are not allowed).
If a signed value is entered here, all selected image numbers are increased or decreased by this value, if a valid image number is available. Example:
Current image number: 31
Input: +1000
New image number: 1031

Station number: Features cameras, which are linked with each other (e.g. stereo cameras) and together represent one recording station. With a value of zero no station is associated with the image.

Camera: Name of the camera to be assigned to the selected images.

File: Name of the image file to be assigned to the selected image. The button … opens the file manager. After the assignment of a new image file, an associated camera is de-allocated if necessary, if the newly imported image size is different from the sensor size of the existing camera.

The check box ☑ indicates whether the image is active. Non-active images are not used in calculations and visualizations.

The assignment of the changed values for the selected images is done by pressing the button  . With  the assigned camera is removed from the selected images.

The button Reassign updates the existing camera assignments of the images with the current camera data that may have changed in the meantime. If no camera is selected, the values for the sensor format are recalculated for the selected images.

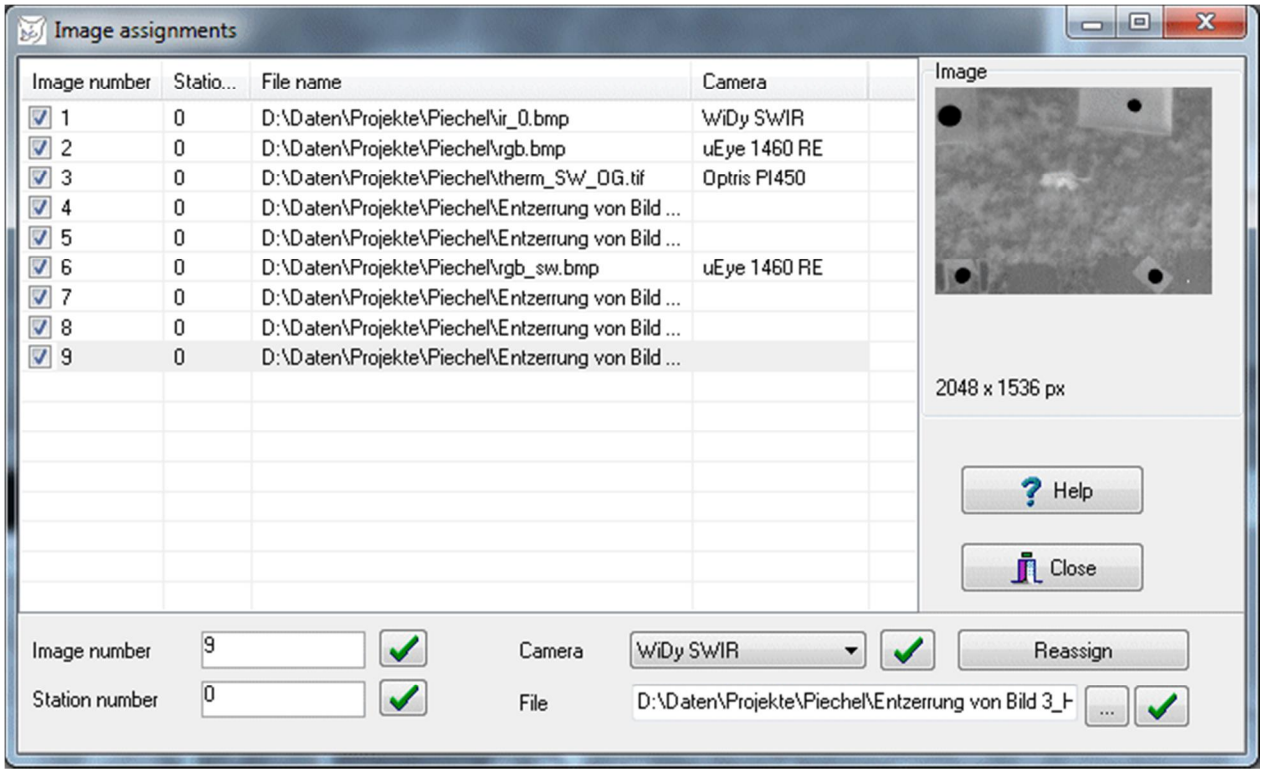


Fig. 47: Image assignments

The image list can be sorted by clicking the column headings. The corresponding popup menu **Sort** changes the internal order of stored images so that it corresponds to the sorted list.

5.8 Create thumb images

Menu:	Images→ Create thumb images
Precondition:	Existing image with bitmap

The function **Create thumb images** calculates thumbnail images of all images in the image list. The thumbnails have a maximum width of 100 pixels and will be saved in the same directory as the original images with prefix $$_ for the file name. Thumbnail images are also required by the function **Graphics/VRML viewer** if the option *Image display* is activated for 3D visualization under **Edit/Options/Visualization/Objects**.

5.9 Properties

Menu:	Images→ Properties
Project tree:	Popup menu under the node Images
Precondition:	Existing image object

The function **Properties** opens a window for the display of various properties and data that are available for the currently selected image.

With the buttons  the previous or next image in the list is selected whereby previous changes made to the current image are stored. With the button OK all changes are accepted and applied to the image. The button Close closes the window without changing the image data.

5.9.1 Image

The page **Image** contains the following information.

Under File information about the image file are displayed.

Filename	Name of the file. It can be changed after confirmation with Rename
Folder	Directory where the file is stored
Last saved	Date and time when the file has been saved
Image size	Number of columns and rows of the image
Color depth	Number of bits per pixel
Image number	Unique image number (integer). The image number can be changed here, whereby already assigned numbers will not be accepted. With the button the next free image number is displayed. The checkbox ☑ indicates if the image is active.
Description	Any text about the image which will be shown in the project tree below the image name

Under Camera information data about the used camera is displayed.

Camera:	Lists information, which is read from a jpg EXIF header. If no EXIF information is available, no data is displayed.
Acquisition time	Date and time of image recording
Exposure time	Exposure time of the image
Aperture	Aperture (f-stop) of the image
Focal length	Focal length of the camera
ISO number	Sensitivity of the sensor
Pixel size	Physical size of a sensor pixel (in mm). The arrow key allows for the calculation of the image format from the given pixel size and bitmap size.
Image format	Physical size of a sensor format (in mm). The arrow key allows for the calculation of pixel sizes according to the given bitmap size and image format.
Sensor format	Number of columns and rows

Under Histogram the distribution of color values of the image is displayed for all available color channels, specifying the minimum and maximum color value, mean and standard deviation (Sigma).

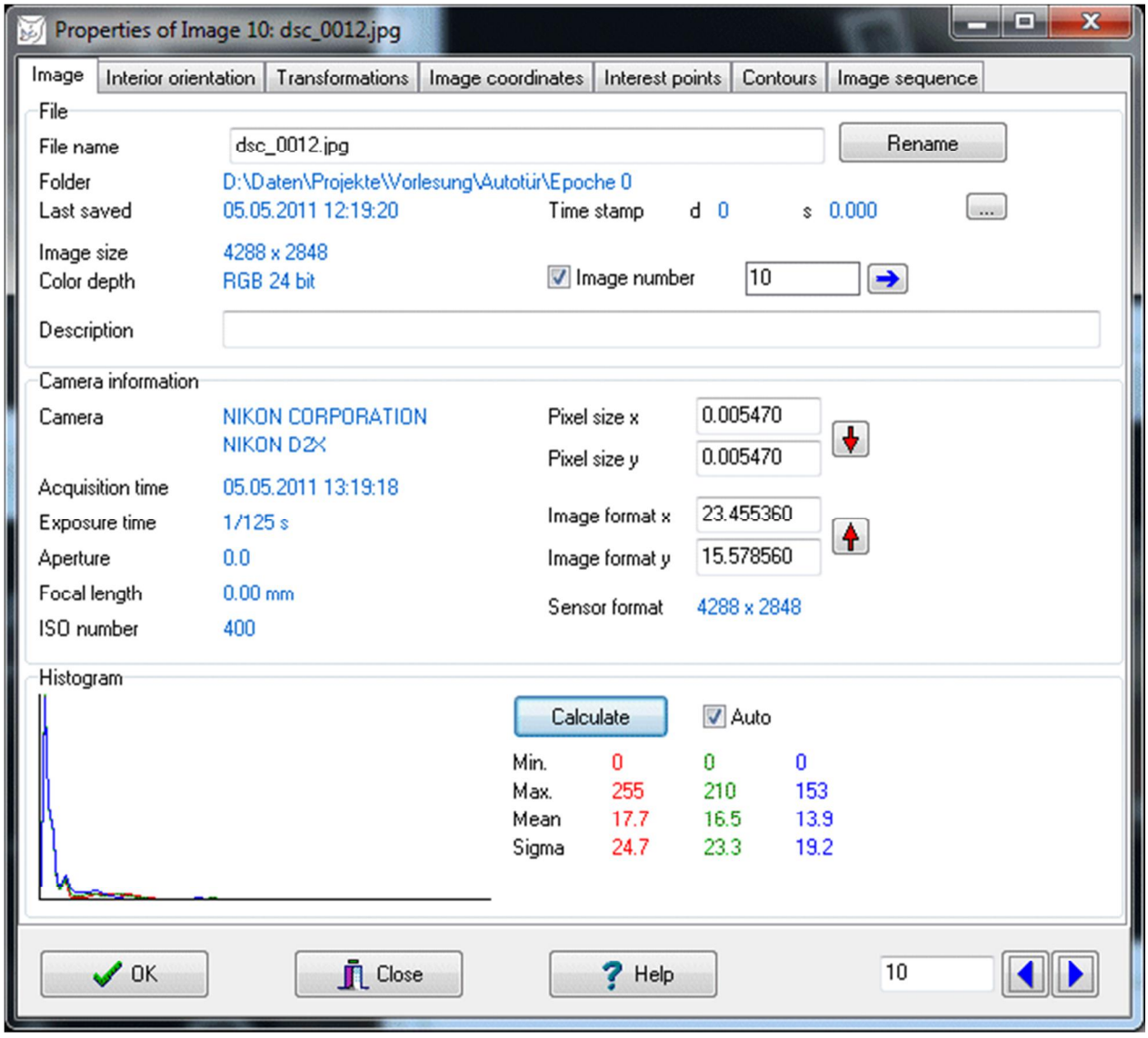


Fig. 48: Image properties: File and image information

5.9.2 Interior orientation

The page **Interior orientation** contains information about the parameters of interior orientation of the current image (calibration parameters). This data is usually a copy of the assigned data of a camera file, but can be changed for individual settings or if no camera is associated.

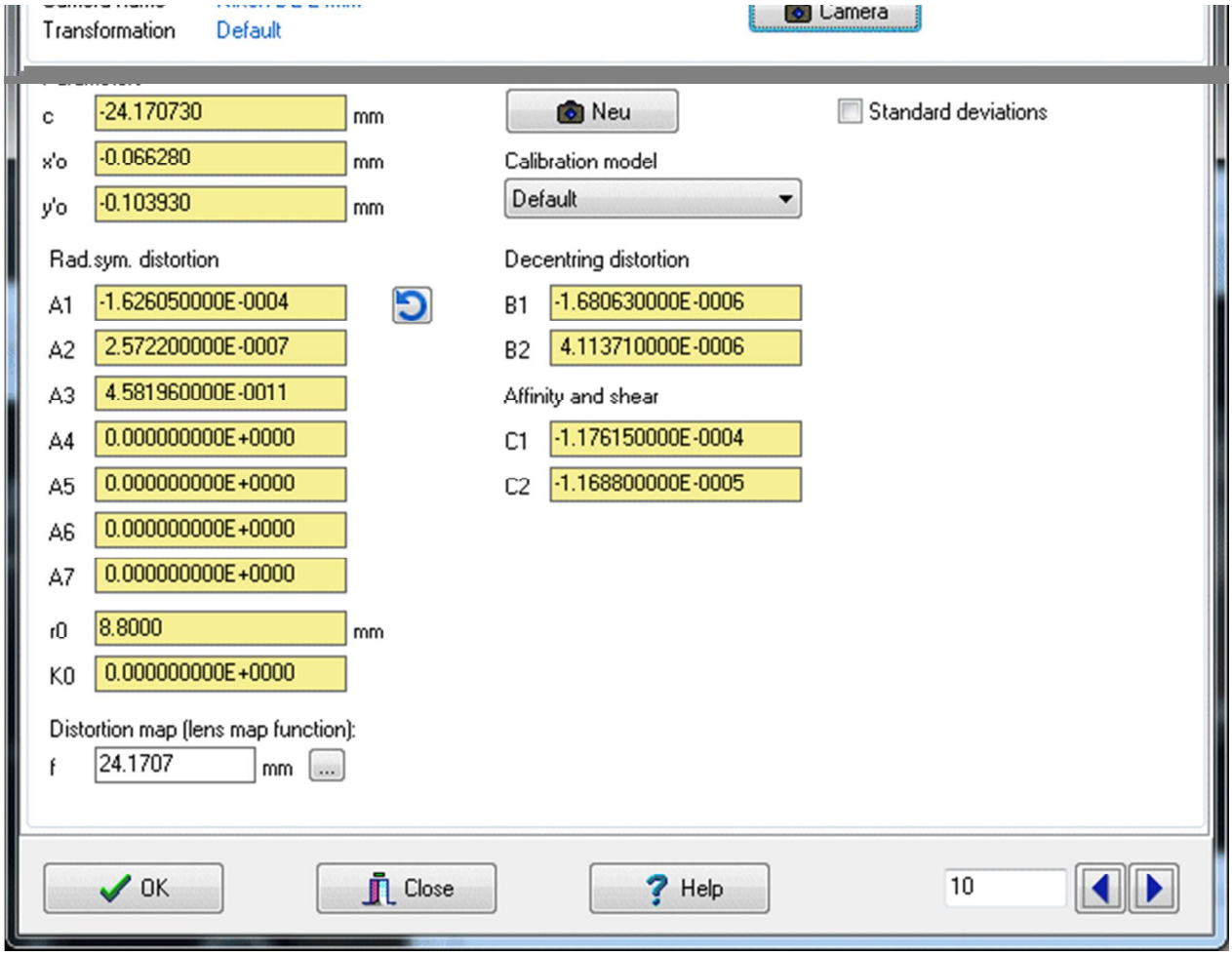


Fig. 49: Image properties: Interior orientation

Under Camera information about the associated camera is displayed.

Camera name: Name of the assigned camera.

Transformation: Type of transformation for pixel to image coordinate transformation

Camera Opens the camera window.

Under Parameters the parameters of interior orientation are listed (see **Cameras/Parameters** for further explanation). With the button New the current data of interior orientation can be assigned to a new camera, which will then appear in the camera list under the name the current image.

c:	Principal distance (camera constant). Must be negative, non-null value in the unit of the image coordinate system (
x'o, y'o	Coordinates of the principal point in the image coordinate system
A1 … A7	Coefficients of radial-symmetric distortion polynomial (usually A1…A3 are used)
r0	Second zero-crossing of a balanced radial-distortion function (can be 0)
K0	Linear component of the radial-symmetric distortion polynomial according to Brown
B1, B2	Coefficients of asymmetric and tangential (decentring) distortion
C1, C2	Coefficients for affinity and shear of the imaging sensor
Distortion map:	Name of an optional file containing a lens map function (table of radius-depended distortion values). The file can be loaded with the button …
f	Focal length used for the lens map function
Calibration model	Defines the mathematical model for interior orientation
Standard deviation	If this checkbox is activated, the entered values are interpreted as standard deviation of the actual interior orientation parameters.

The button  resets the distortion parameters to zero.

5.9.3 Transformations

The page **Transformations** contains the exterior orientation of the current image and transformation parameters.

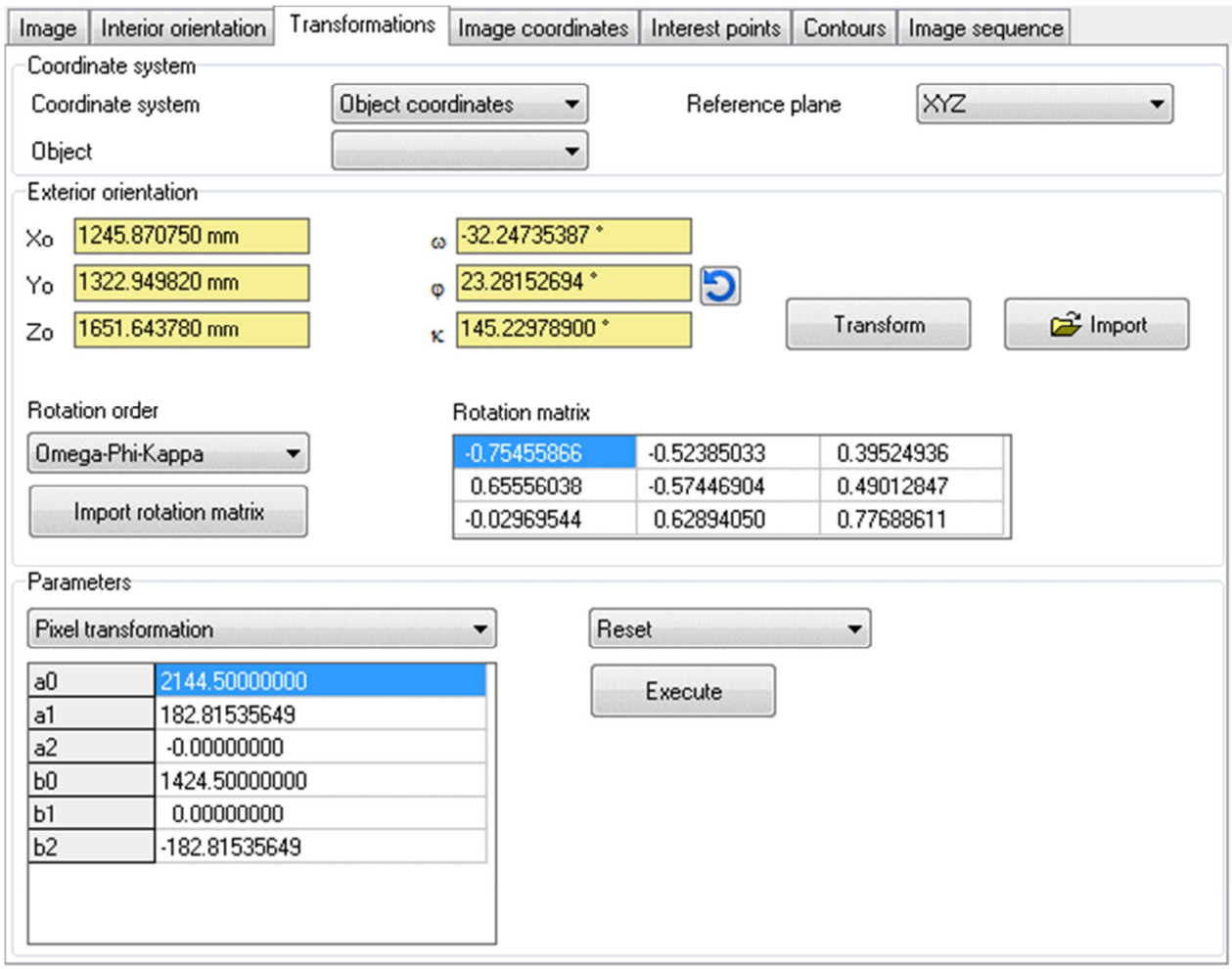


Fig. 50: Image properties: Transformations

Under Coordinate system the following settings are made:

Coordinate system: Coordinate system to which the exterior orientation refers to (default: object coordinate system).
Image coordinates: initial definition for an image without relationship to object space
Model coordinates: exterior orientation given in a stereo model system xyz
Object coordinate system: exterior orientation given in a world or object coordinate system XYZ
Projective: transformation between image and object plane by 8 parameter projective transformation
Object model: not implemented
No system: not implemented

Object: Not implemented

Reference plane: Main coordinate plane, in which an image is being rectified (default: XYZ = no plane defined)

Under Exterior orientation the exterior orientation parameters are displayed:

Xo, Yo, Zo: Editable values of translation

ω, φ, κ Editable values of rotation angles

Rotation order: Order of the Euler rotations (Default: ω, φ, κ around X, Y, Z)

Rotation matrix Rotation matrix of the selected rotation angles and rotational order

The switch resets all values to zero.

With Import rotation matrix the rotation matrix can be read through a text file, in which per input line the three coefficients (separated by spaces) must be stored for the corresponding row of the matrix. After reading the corresponding rotation angles are determined from the rotation matrix.

With Transform a dialog is opened where the conversion factors for the translation and rotation angles of the exterior orientation can be set and applied to the image.

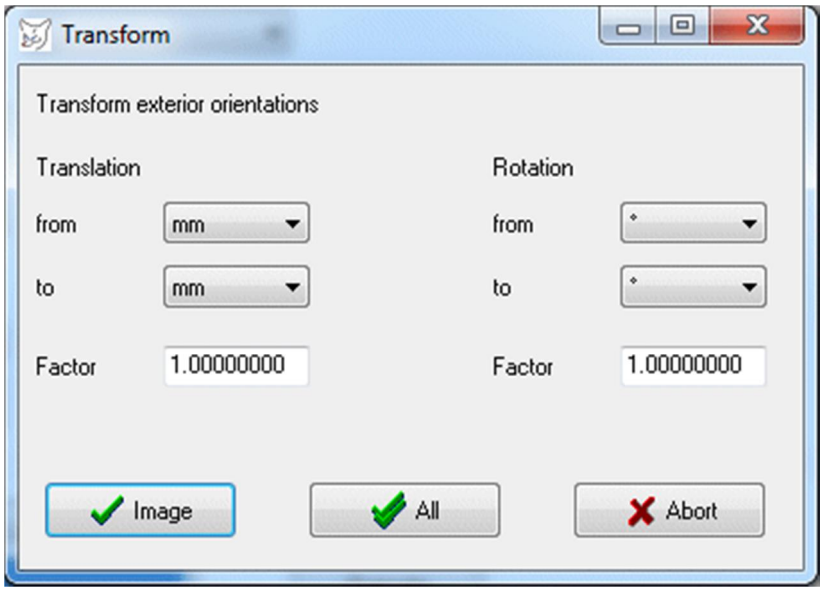


Fig. 51: Image properties: Transformation of exterior orientations

The conversion factors arise from the selected units or the value in the *Factor* box. The orientation data are multiplied by this value. Hence, it is for example possible to transform the orientation values imported with an incorrect unit into another unit. With Image only the currently selected image will be converted, with All all images will be converted.

With Import parameters of exterior orientation can be loaded to the current image. In contrast to the function **Project/Import/Orientations** here, independently of the current image number, the set of orientation parameters will be loaded which is found at first in the selected file.

Using the popup menu data of exterior orientation can be copied or pasted.

Copy Copies the displayed data into a temporary memory

Paste Pastes the copied data as new exterior orientation of the current image

Under Parameters a list of various 2D transformation parameters associated with the image is displayed. The transformation values cannot be edited.

Pixel transformation:	6 parameters of affine transformation for the conversion of pixel coordinates to metric image coordinates
Projective transformation:	8 parameters of the plane projective transformation for the rectification of the image on a selected object plane
3D projective transformation:	12 parameters of spatial projective transformation, currently not implemented.

The switch Execute resets the transformation parameters in accordance with the above selection:

Reset:	All transformation parameters are set to 0, and a1 and b2 to 1.
u,v[px] > x'y' [px]:	The parameters of the transformation of the pixels are calculated so that the metric image coordinates to pixel units are represented.
u,v[px] > x'y' [mm]:	The parameters of the transformation of the pixels are calculated so that the metric image coordinates of millimeters according to the sensor format are represented.

5.9.4 Image coordinates

The page **Image coordinates** lists the image points stored to the current image. For each point the integer point number, the image coordinates x',y', an integer code, standard deviations sx', sy' and optionally distortion values are displayed. The check box ☑ indicates whether the point is active. Non-active points are suppressed in graphical outputs and some calculations.

The popup menu associated with the coordinate list provides the following functions:

New	Generates a new image point
Edit	Editing of the selected point
Delete	Deletes all selected points
Activate	All selected points are activated
Deactivate	All selected image points are disabled
Select all	Selects all image points
Toggle selection	Inverts the point selection
Point selection	Open a window for individual point selection
Check image format	Select all points that lie within the image format
Sort	Rewrites the point list in the currently displayed sorting; by clicking on the column headings, each column can be sorted alphabetically ascending or descending.
Copy	Copies all selected points into an internal cache memory
Paste	Copies all points from the cache into the existing list. Existing point numbers are not overwritten, new points are added to the end of the list
Show lens distortion	Adds new columns with the values for the image radius r' and the associated distortion correction dr', its effect in x'- und y'-direction dx' and dy', as well as the corrected (distortion-free) image coordinates x_corr and y_corr.
Pixel coordinates	Displays the coordinates of the point in pixel units; otherwise they are displayed in the unit associated with the interior orientation (usually mm).
Copy table	Copies all selected points in Excel format into the Windows clipboard.

With Import image coordinates of external files can be loaded according to the function **Project/Import/Image coordinates**.

The button Filter opens the dialog of function **Objects/Filter** for the filtering of image points.

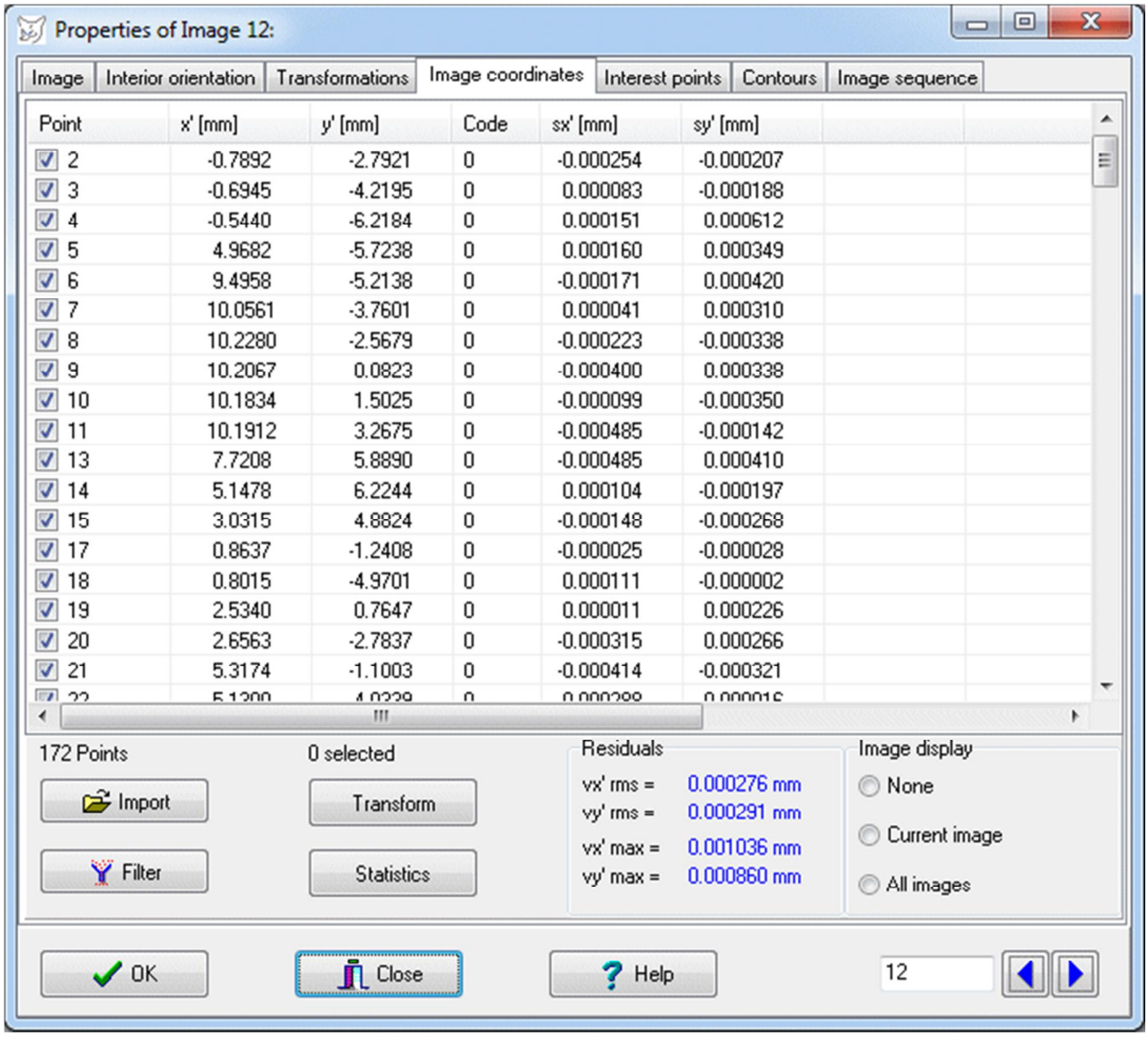


Fig. 52: Image properties: image coordinates

The button Transform opens a window for the conversion of image coordinates. In this dialog several ways of coordinate transformations are available:

Image selection: Selection between the *current image* or *all images* of the project. If *selected points only* is activated, only selected points of the current coordinate list are transformed.

Transformation: Conversion of image coordinates to pixel coordinates and vice versa on the basis of the stored pixel transformation; exchange of x' and y' image coordinates; or linear transformation with the entered values.

Interior orientation: The selected parameters of interior orientation can be applied to the image coordinates, i.e. for example, error-free image coordinates can be affected with the

distortion values to display them correctly in the image window. Alternatively, distorted image coordinates can be corrected, i.e. they are then free of aberrations.

Storage: The converted image coordinates are either overwritten (original data will be lost) or appended as additional image points to the existing list.

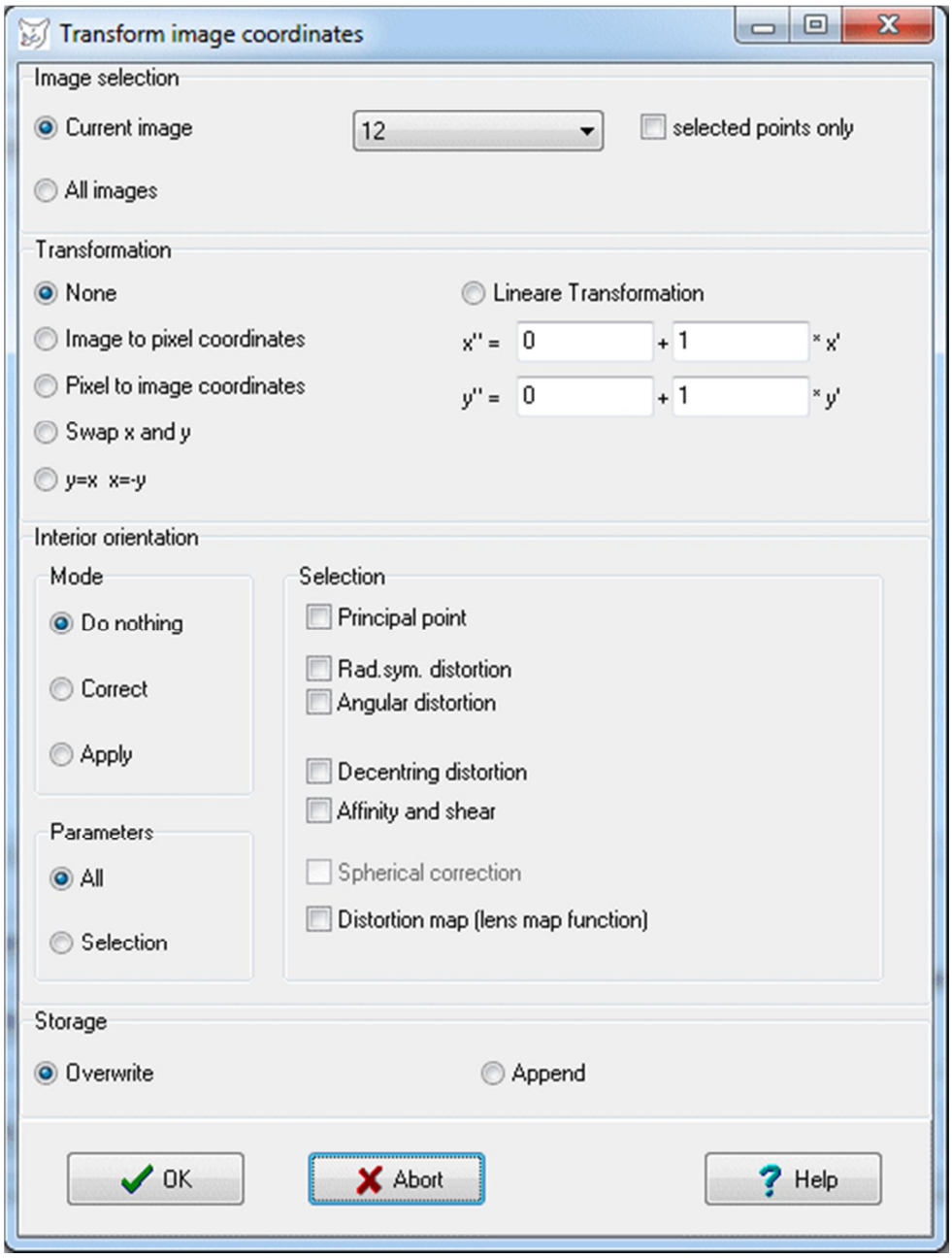


Fig. 53: Dialog for the conversion of image coordinates

Under Residuals the average and maximum residuals (standard deviations) of all points are listed. This data can be the updated with Statistics.

The options under Image display are used to display the currently selected image point in the associated image or in all images.

5.9.5 Interest points

The page **Interest points** is used for the display and management of points that have been measured by an interest operator. Since there may be a lot of points of interest depending on the operator, they are stored in a separate data structure.

Properties displays the characteristics of measured interest points.

Number of points: Number of interest points that are stored for the current image.

Image coordinates: Transfers all the points of interest into the list of image coordinates. Overwrites any existing image points.

Delete: Deletes all the points of interest.

Display: Displays all the points of interest in the box below.

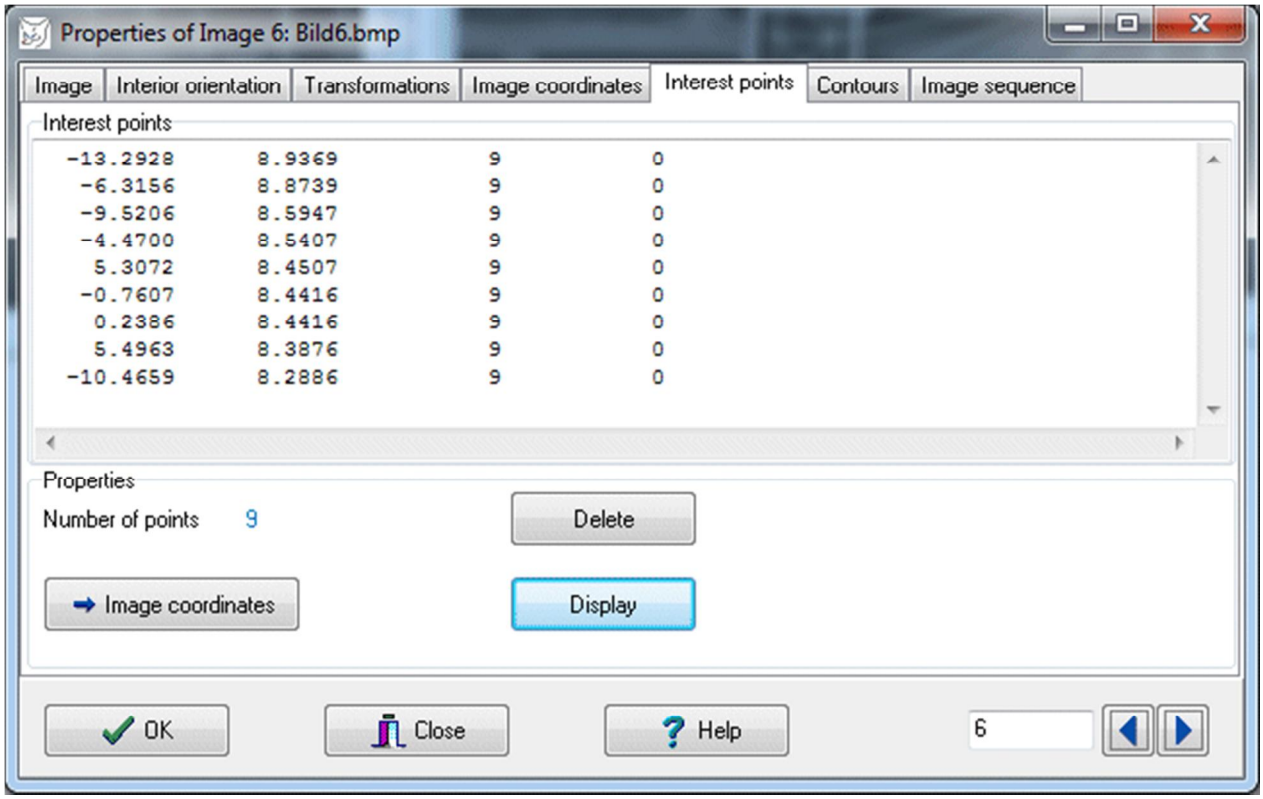


Fig. 54: Interest points

5.9.6 Contours

The page **Contours** is used for the display and management of image contours that have been measured by a contour tracking. Contour points are stored in a separate data structure.

In the popup menu, the following functions available are:

New Creates a new contour

Delete Deletes the selected contour

Edit Represents the points associated with the selected contour. The image points can be subsequently edited or deleted.

The characteristics and parameters of the contours are displayed under *Properties*.

Name: Name of the selected shape. Any name can be entered here.

Method: The contour edge type:
Ramp: The outline is represented by a striking grey value jump between a light and a dark range of gray values. The respective edge point is the zero-crossing of the second derivative.
Line: The contour is a line, i.e. a narrow change of light-to-dark-to-light or dark-to-light-to-dark. The respective edge point is the zero-crossing of the first derivative.

Number of nodes: Number of polygon points that control the progression of the contour. The points can be deleted with ✕.

Number of points: Number of contour points which have been measured for the contour. The points can be deleted with ✕

Profile length: Length of the transverse profile in pixels in which the edge point is searched.

Step width: Maximum increment of contour tracking in pixels. The step size is automatically reduced when measuring at narrow contour gradients.

Max. number Maximum permitted number of contour points

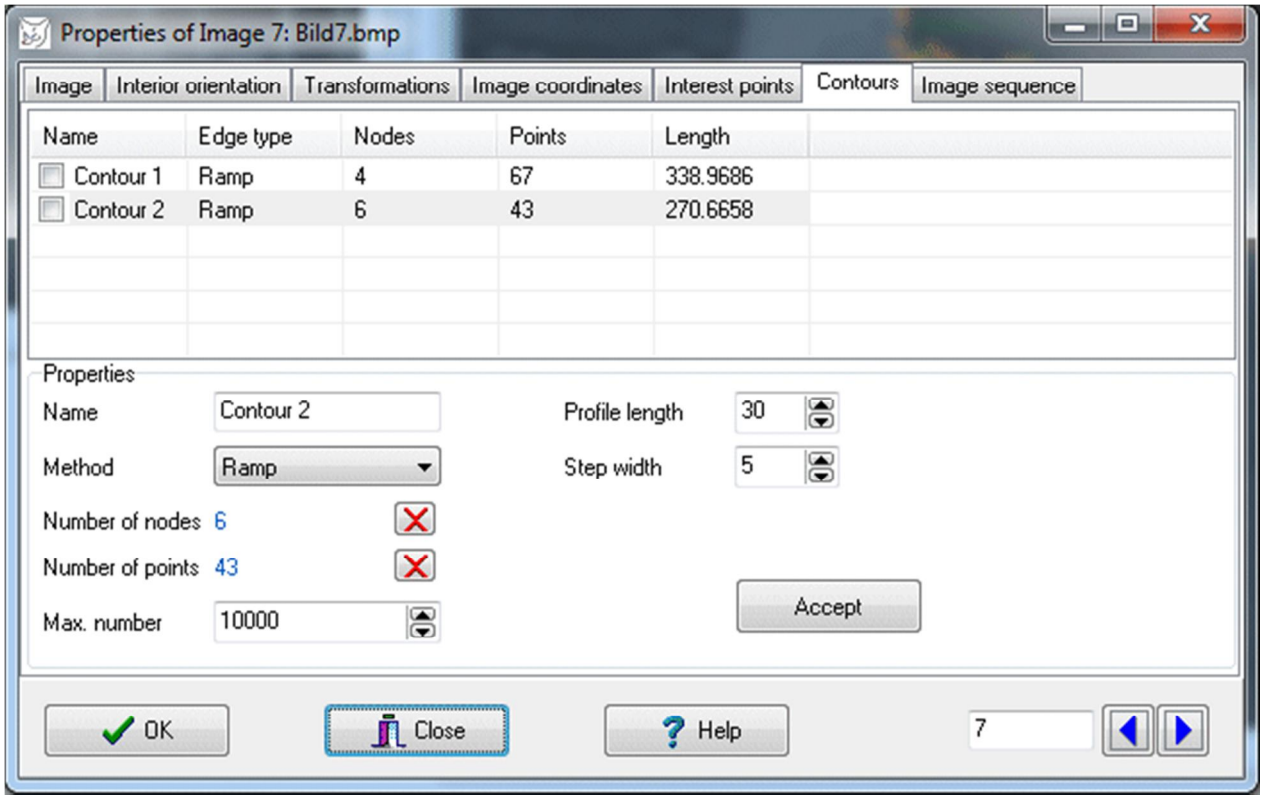


Fig. 55: Image properties: Contours

With Accept newly entered parameters are stored for the selected contour.

5.9.7 Image sequence

The page **Image sequence** is used to display and manage the images of an image sequence belonging to the image object. A sequence consists of as many images of same size as the original image (bitmap). The sequence may arise from a batch processing, which processes the original image with one or more image processing functions. Each intermediate result is stored as an image of the sequence.

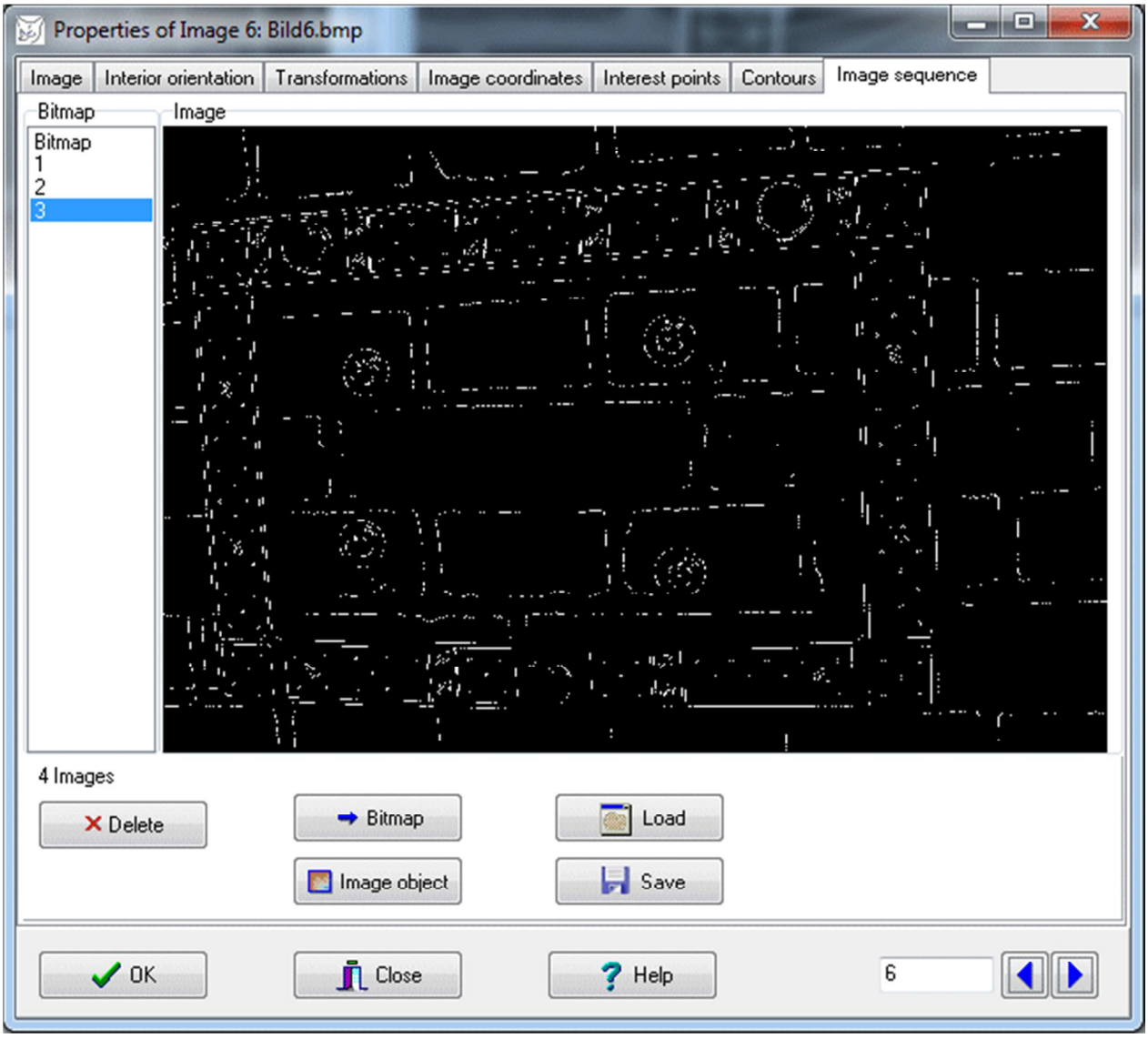


Fig. 56: Image sequence

Under Bitmap the original image (bitmap) as well as existing images in the image sequence are listed. By clicking on the image number it will be shown under Image. With the button Delete all selected images can be deleted (except the original image). With Bitmap the selected image bitmap is associated with the original image, i.e. the bitmap of the original image will be replaced. With the button Image object all selected images will be stored as a new image objects with the properties of the current image.

With Load any number of image files can be added to the image sequence. They must have the same image size as the original bitmap. With Save the marked images in the image sequence can be stored into individual image files. They are continuously named according to the scheme "filename # n", where n is the number of the list item of the image.

5.10 Delete coordinates

Menu:	Images → Delete coordinates
Precondition:	Existing image with image coordinates

The function **Delete coordinates** deletes all image coordinates of the previously selected images. The function cannot be undone.

5.11 Image processing

Menu:	Images → Image processing
Precondition:	Existing image with bitmap

The function **Image processing** allows the modification of the image content through various image processing methods. The application of these methods changes the image content, but not the data of interior or exterior orientation of an image. Therefore, methods that alter the geometry of the image (e.g. size, rotation, distortion) are not included here. For that purpose the function **Rectification/Image transformation** must be executed.

After the function call a window appears with various image processing functions, which can each be applied to the currently selected images.

Under Images the list of all image objects will be displayed. The topmost selected image appears under *Input image*, where it can be enlarged and scrolled with mouse and wheel. A right mouse click displays the complete image.

Under Process steps a sequence of image processing functions appears. With + a function displayed at the bottom is added to the process list along with their associated settings. With – the selected list items can be deleted.

The button Test executes the currently selected image processing function and represents the result under *Result image*. If the button is permanently activated with ⇩, the result image will be shown immediately after every changed entry. This can cause delays at large images.

The button Preview executes the process list of the topmost selected image and represents the result under *Result image*. The button → executes the process list up to the first selected function.

The button Input copies the current result image into the input image so it can be processed once again.

The button  is used to select an image window (area of interest AOI), in which the image processing operations take place. Only if the AOI mode is active (button is pressed) the image window will be processed, otherwise the entire image is processed.

With *Preset* the functions displayed in the process list can be saved and loaded again. These so-called presets are stored in text files with the extension *.ppp.

The button Start executes the process list for all selected images, the respective final results will be saved under the image object and the window is closed. The bitmap of the image objects are not changed in geometry and therefore the related data of interior orientation remain unchanged. The processed images are stored as bitmaps to the image objects in memory. If the button  is pressed, all processed images will be saved under the old name of the file and removed from main memory. The original images are lost. This mode is suitable when large amounts of image data for multiple images have to be processed.

The button Image object creates a new image object with the bitmap displayed in the result image and the orientation data of the selected image.

With Close closes the window is closed without changing the image objects.

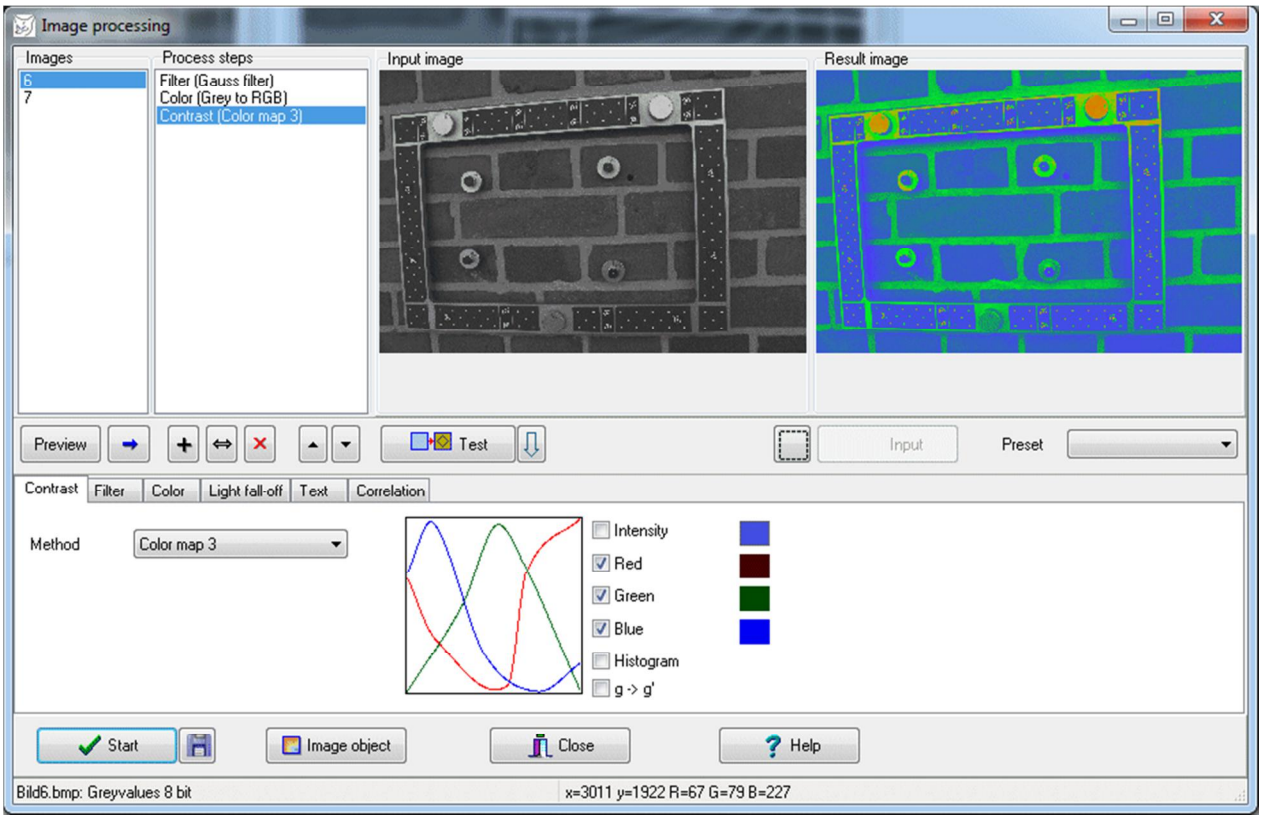


Fig. 57: Window for image processing

The various function groups are described below.

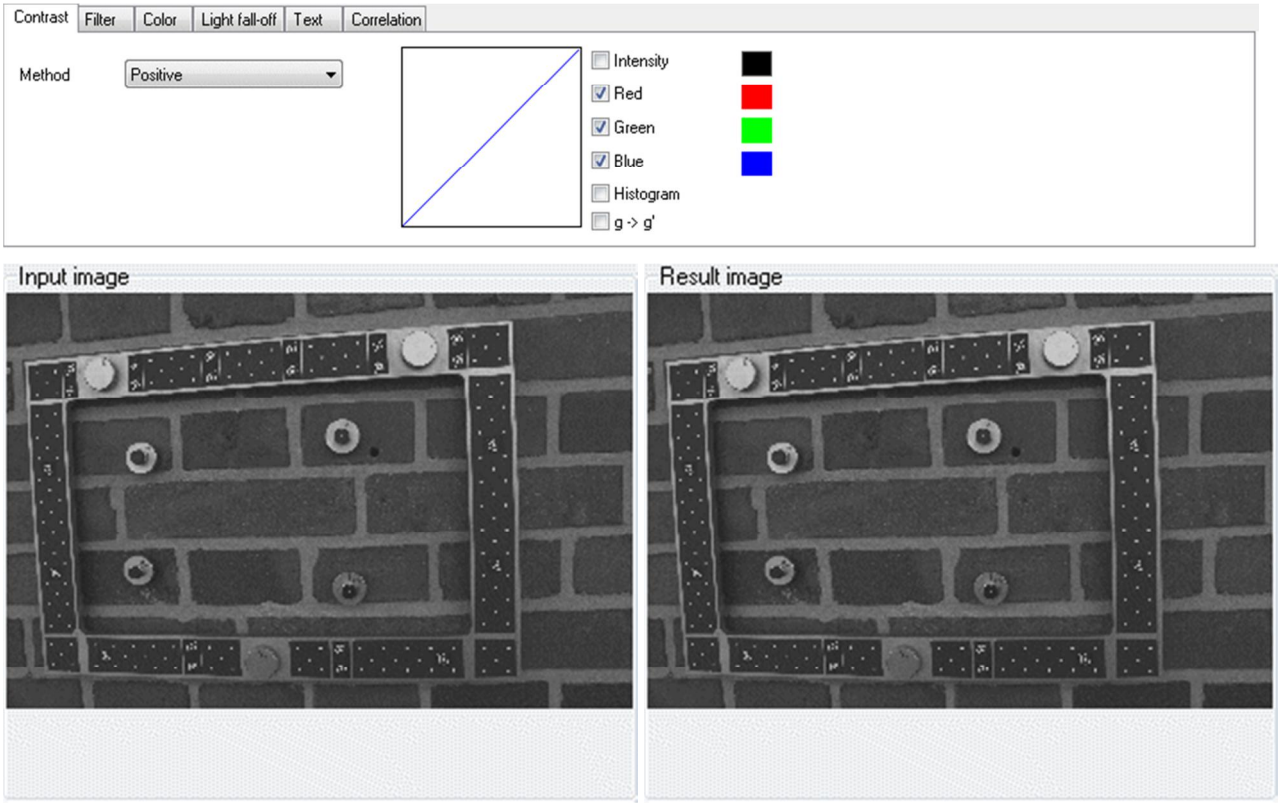
5.11.1 Contrast

Methods for adjustment of contrast, brightness and color of the image are offered here. The selection of the method is done via the drop-down box. The onscreen sliders directly cause a change in a reduced thumbnail. The original image is only processed after pressing Preview.

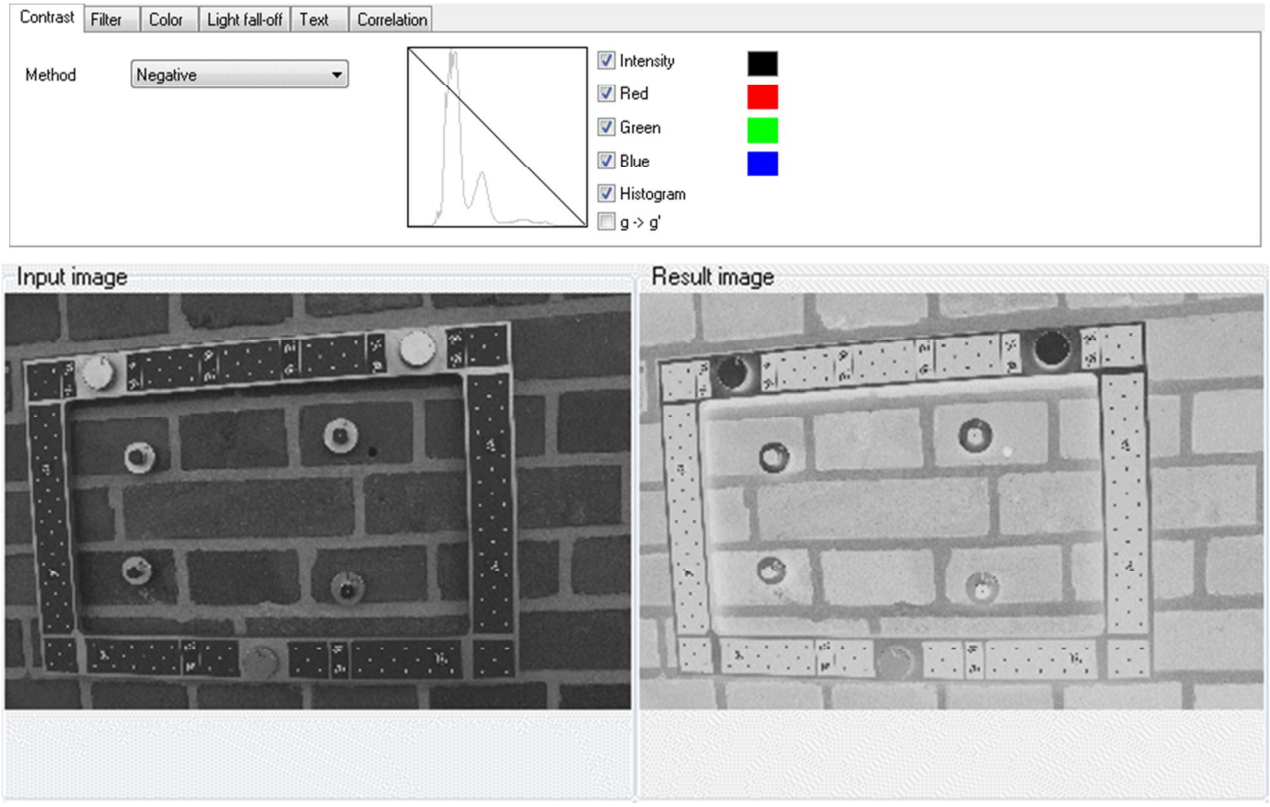
All methods lead to the calculation of a color table (lookup table LUT) which is then used to process the actual image. The color table can be respectively calculated and displayed for the color channels red, green, blue, or the intensity channel (all colors). The histogram of the selected image can optionally be displayed in the graphic. If the switch *g -> g'* is enabled, the color value of the current cursor position in the input image is displayed in the LUT diagram.

Implemented methods:

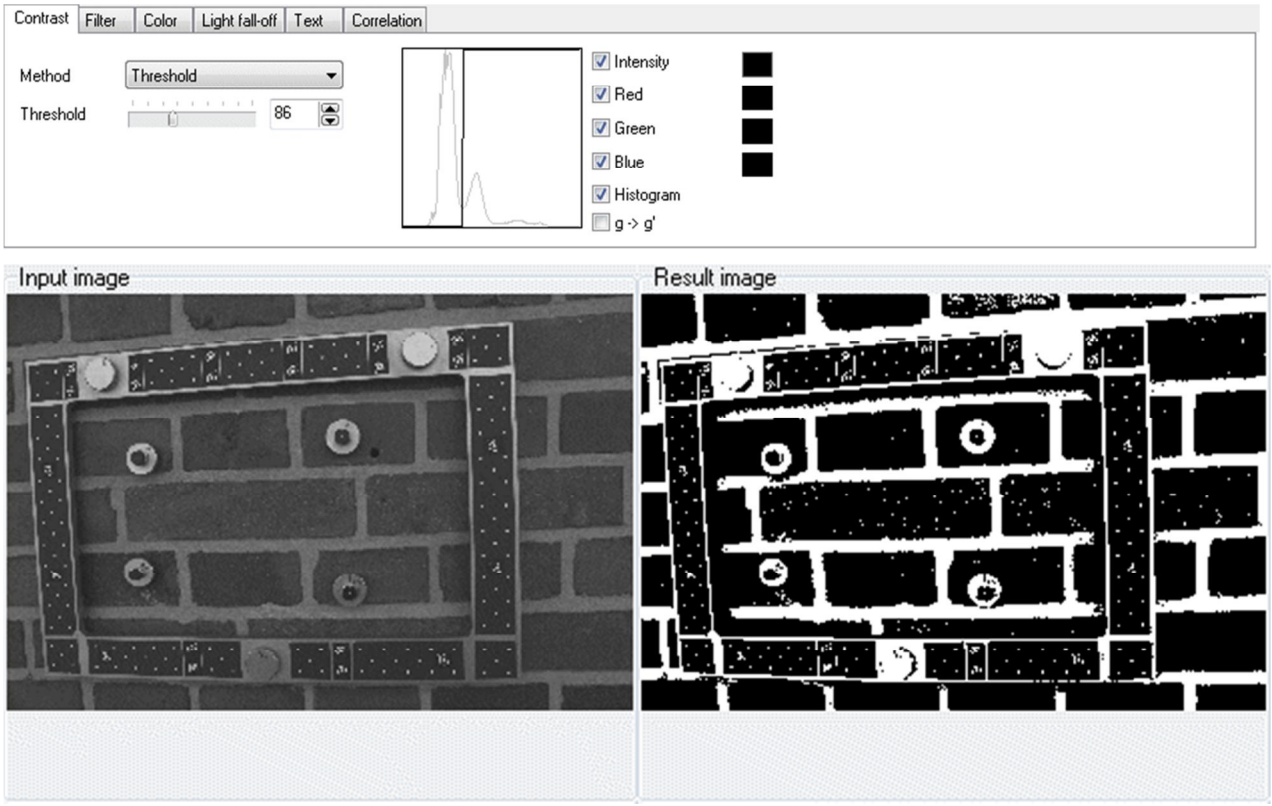
Positive: Linear LUT with slope 1 (no change of the image)



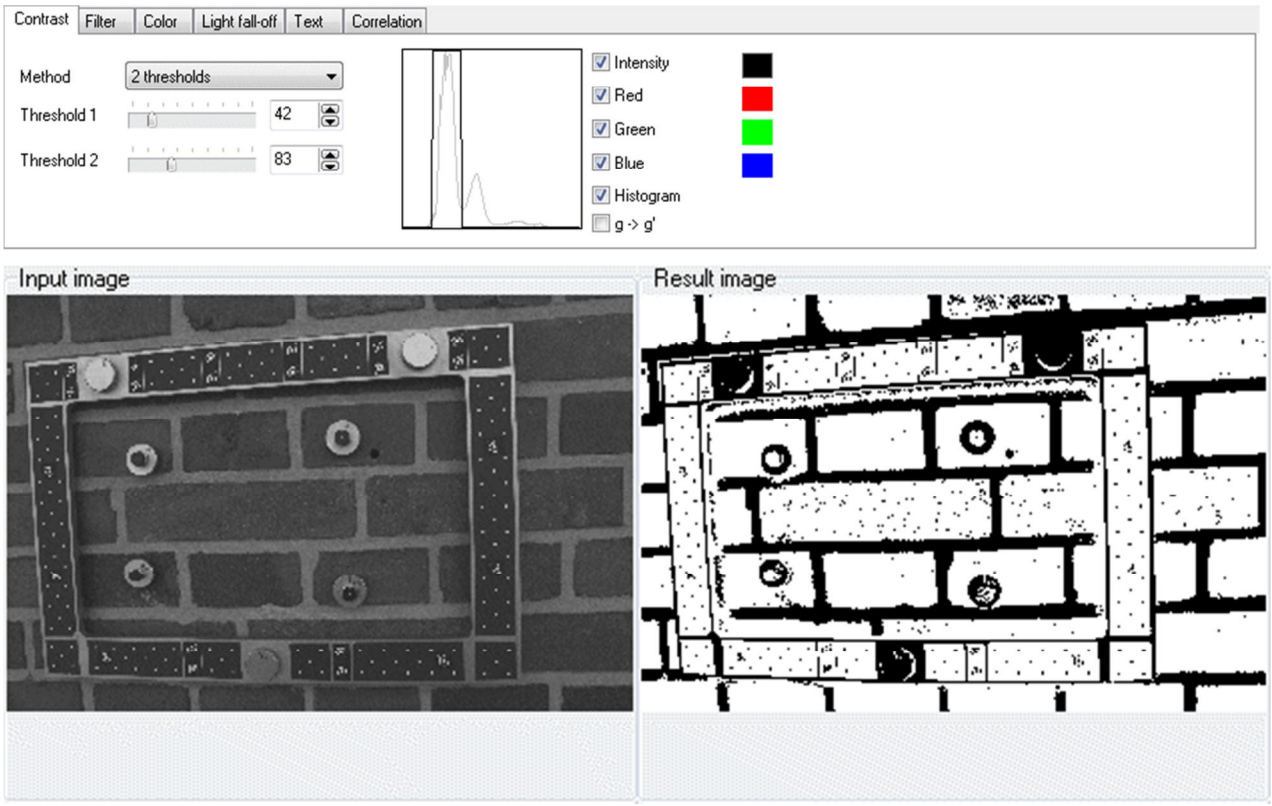
Negative: Linear LUT with slope -1 (negative conversion)



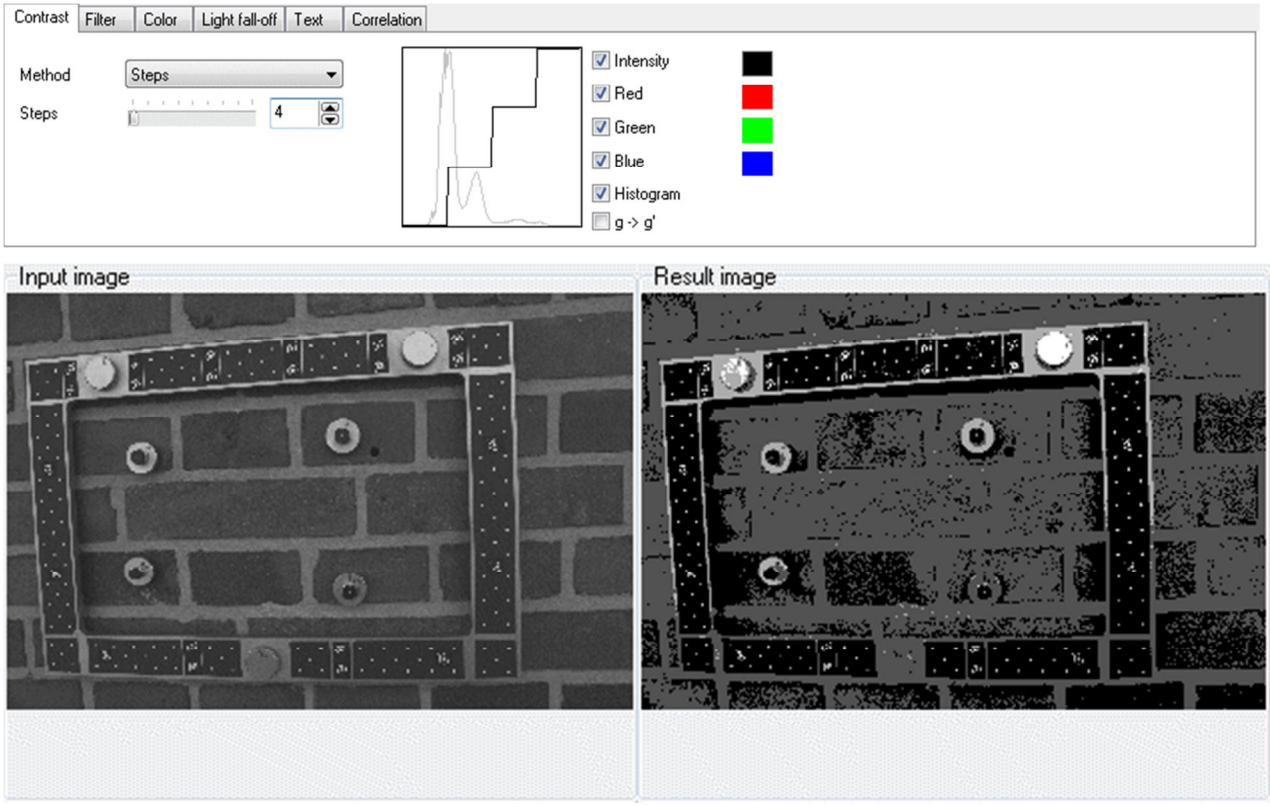
Threshold: Binary image with color value 0 below threshold and color value of 255 above threshold



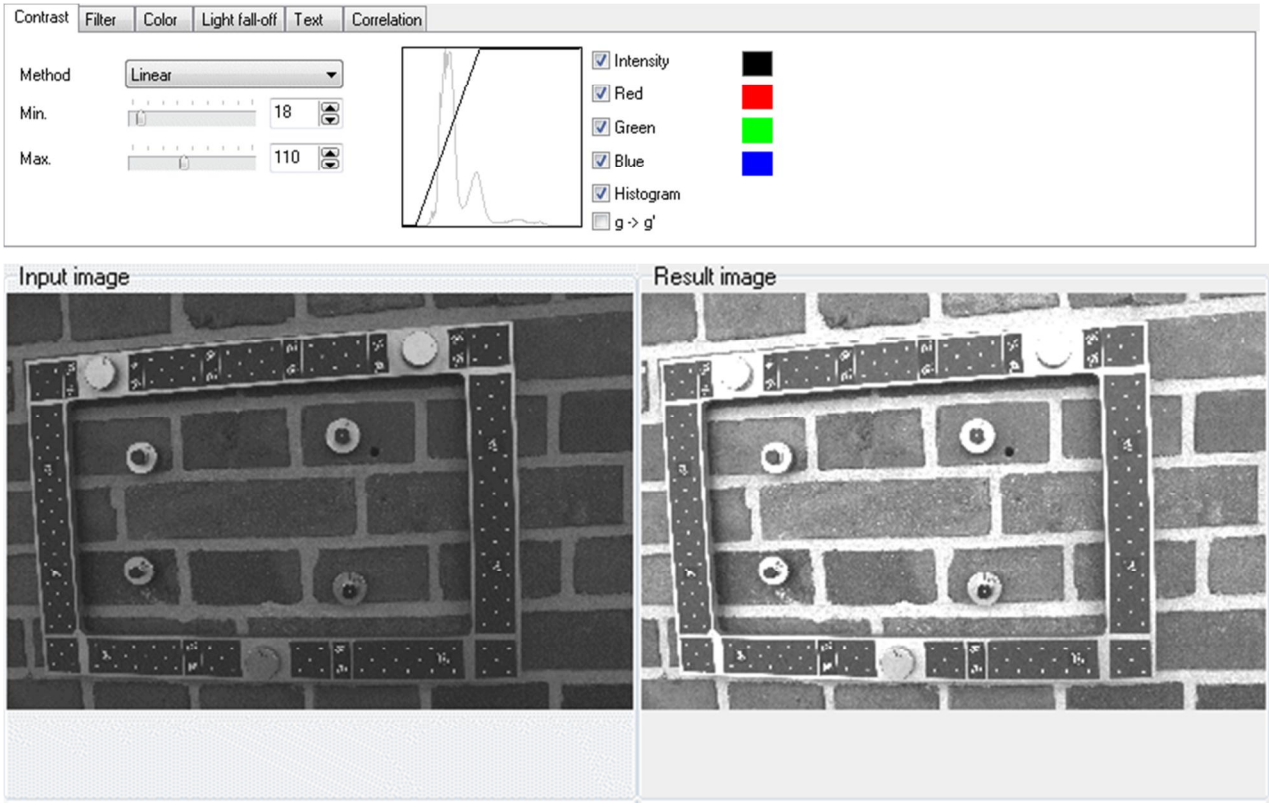
2 thresholds: Binary image with color value 0 below threshold 1, color value of 255 between threshold 1 and threshold 2 and color value of 0 above threshold 2



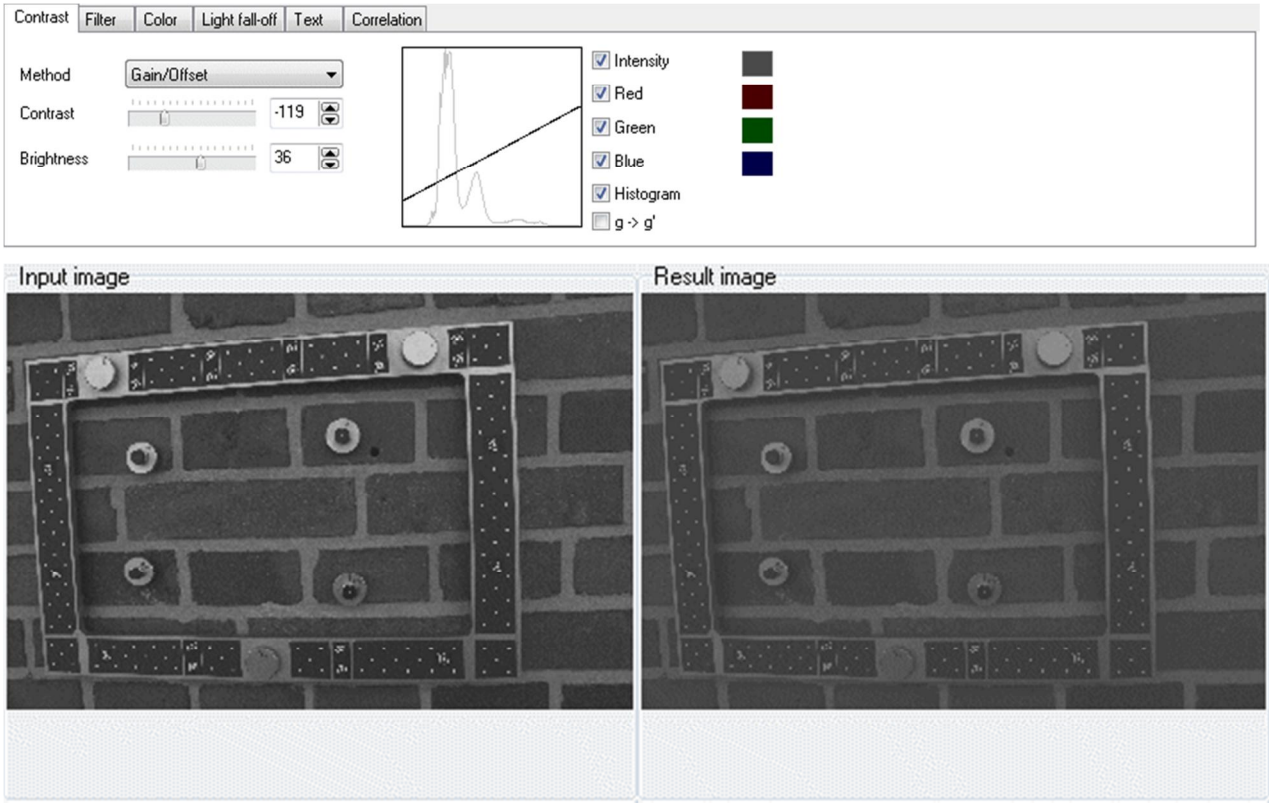
Steps: Reduction of the color range with n levels



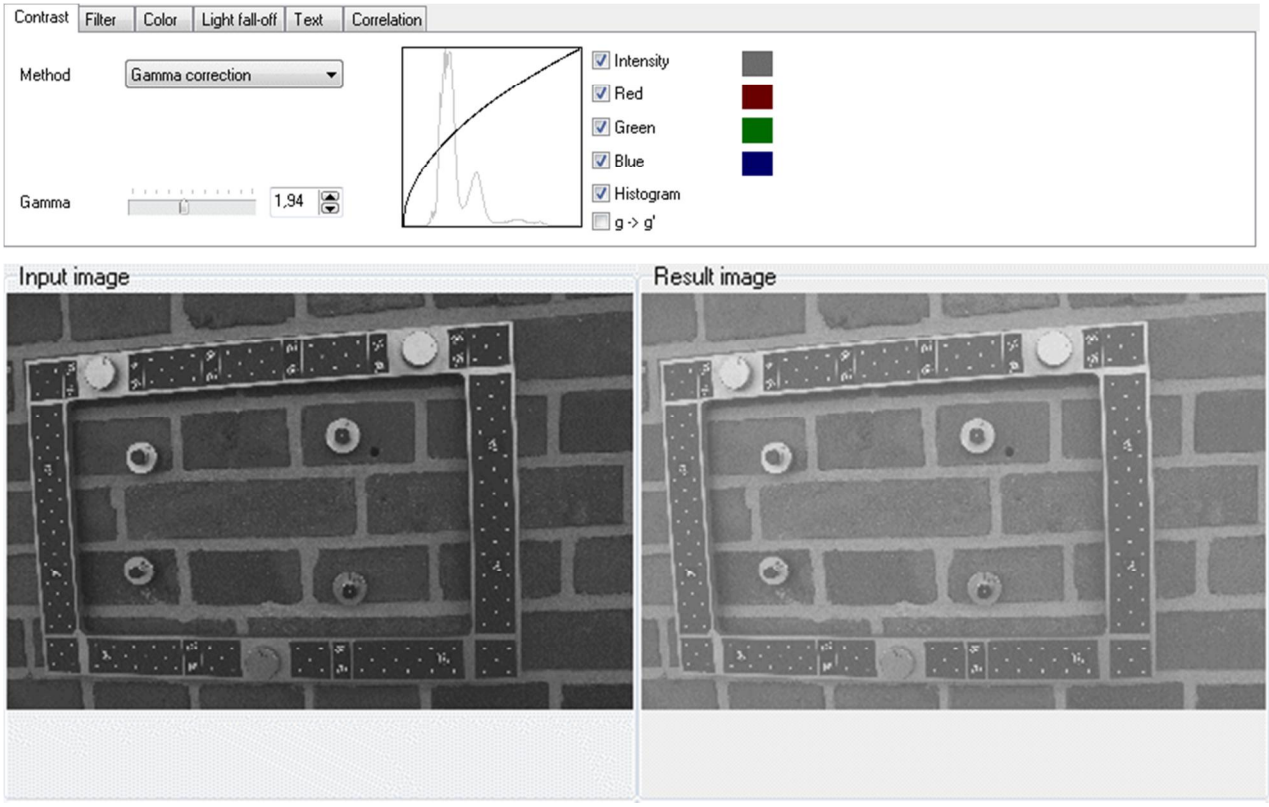
Linear: Linear contrast stretch between *Min*. and *Max*.



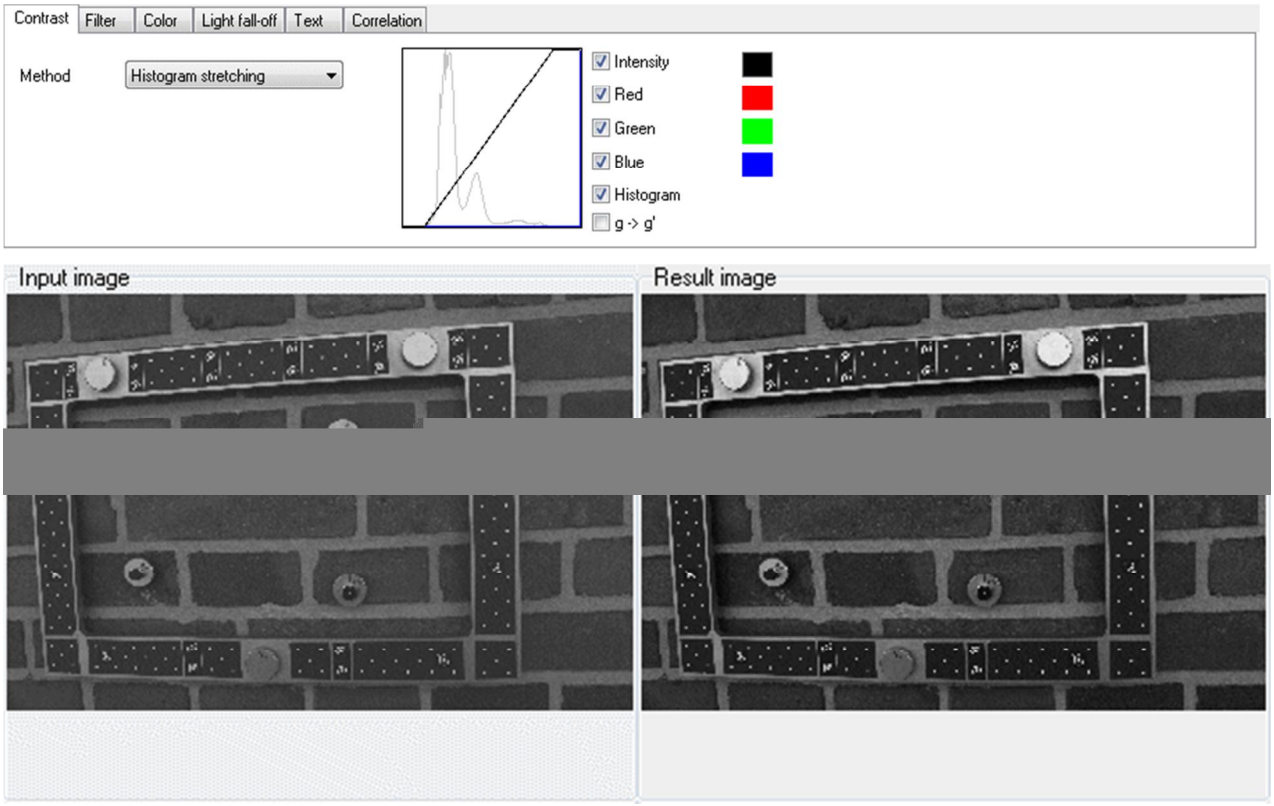
Gain/Offset: Change of brightness and contrast using slider or value



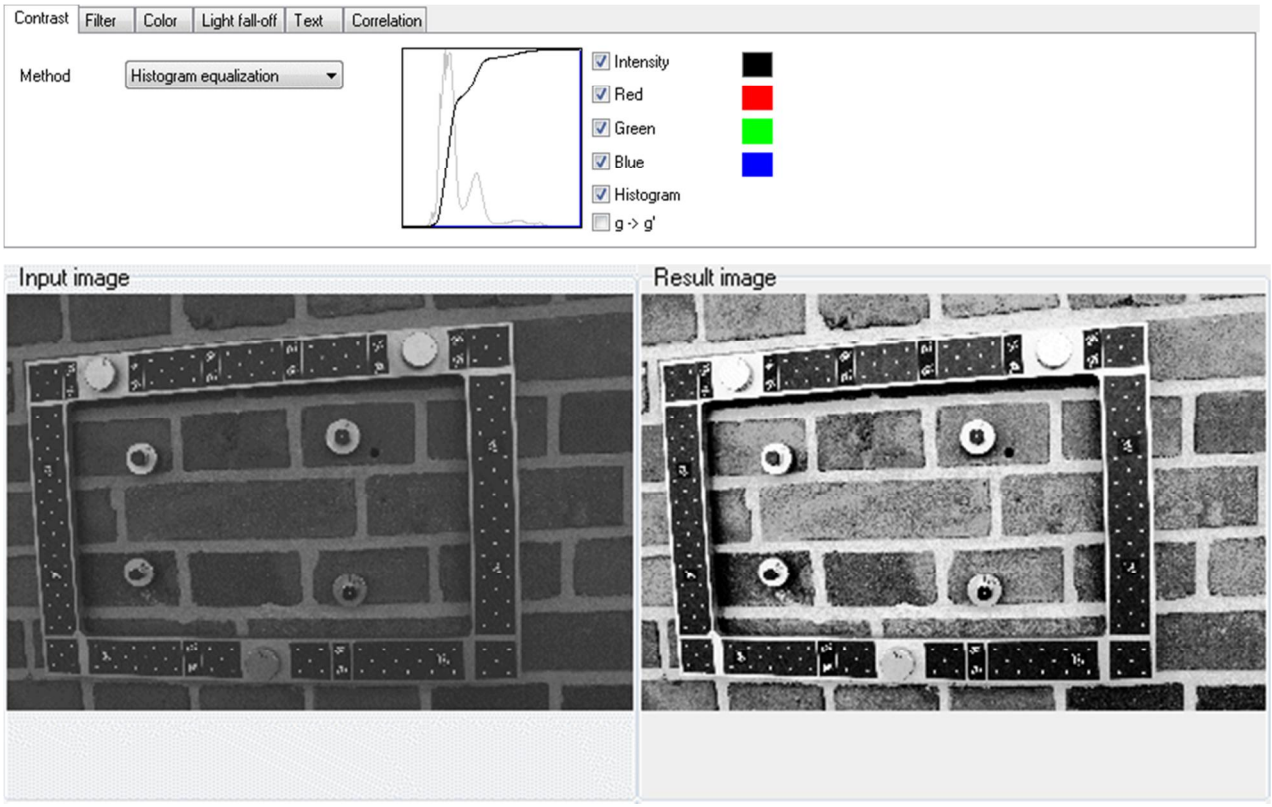
Gamma correction: Change of the gamma curve by slider or value



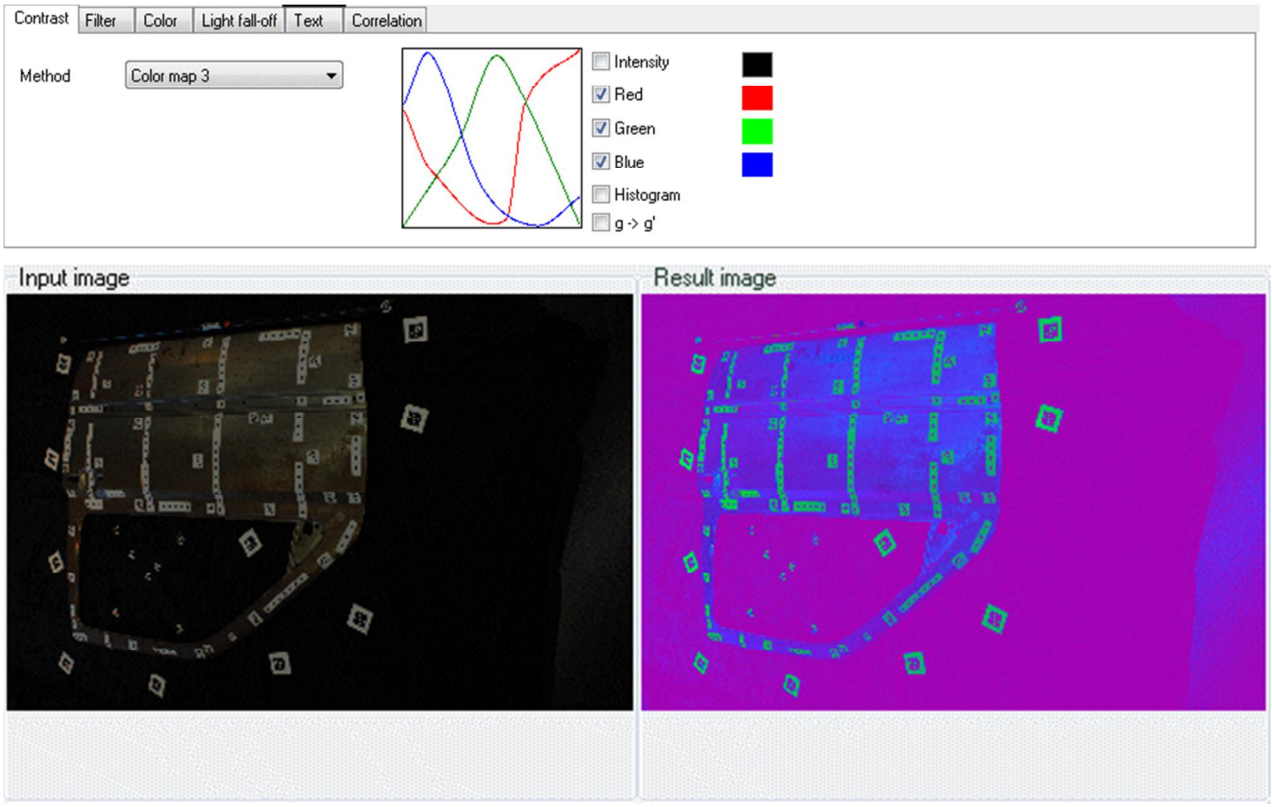
Histogram stretching: Linear contrast stretch between minimum and maximum color value of the corresponding histogram



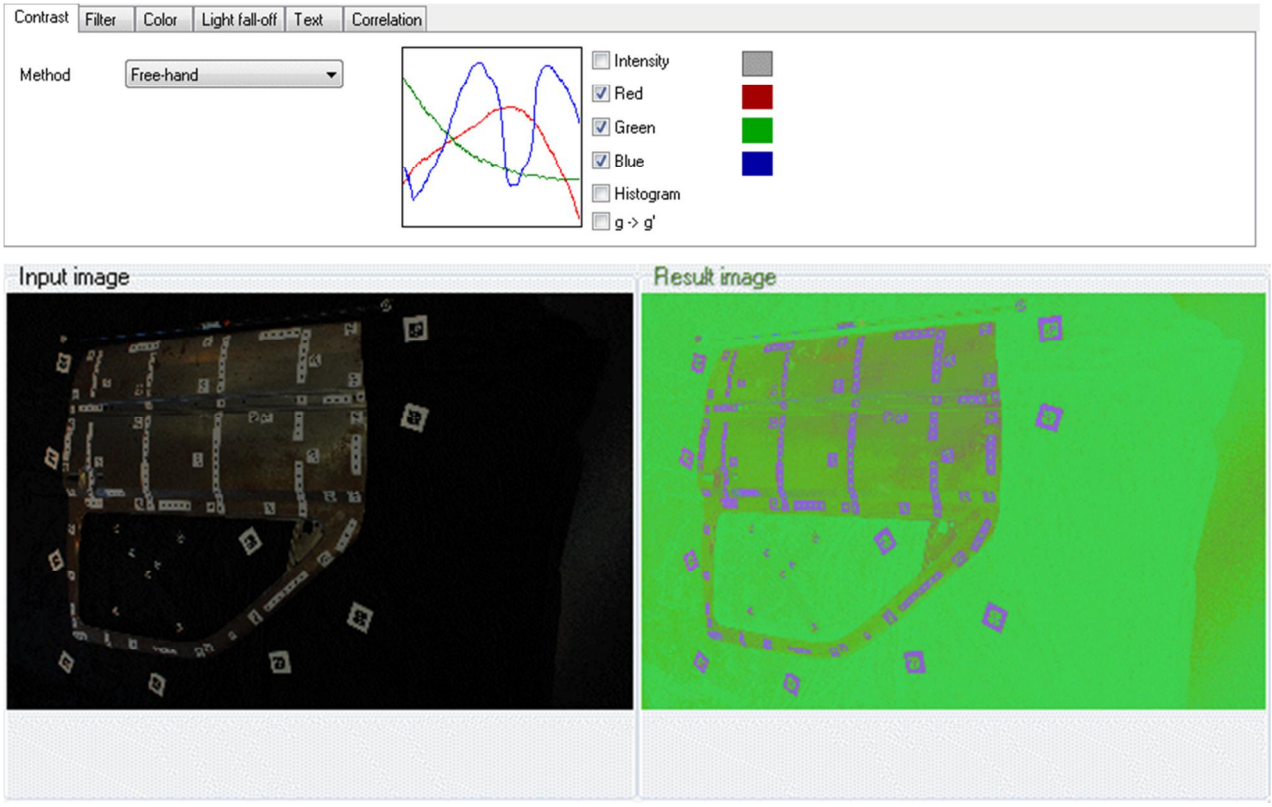
Histogram equalization: Change of the contrast on the basis of the sum frequency function



Color map 1-3: Various color palettes (only for RGB images)



Free-hand: LUT will be drawn interactively with the mouse.



Background color: LUT is calculated according to the color shown in the color box. Any color can be selected by clicking on the color field. Alternatively it can be clicked in one of the images to use the color at the current cursor position.

5.11.2 Filter

Methods for the filtering of the image are offered here. The selection of the method is done via the *Method* drop-down box. There are filters for image smoothing, noise reduction, improvement in sharpness, edge extraction and morphology available. The strength of the filter effect and filter window size can be adjusted. The processing of the image takes place after pressing Preview.

Implemented methods:

Averaging filter: Image smoothing by moving average filter

Gauss filter: Smoothing with Gaussian filter

Median filter: Smoothing and noise pixels removal by median filter

Sharpen: Improving the sharpness

Simple edge filter: Extraction of image edge by one of the following procedures (slider *Effect*):
Simple: 3 x 3 edge filter
Prewitt: Prewitt edge filters
High pass: simple Laplace filter

Enhanced edge filter: Extraction of image edge by one of the following procedures (slider *Effect*):
Marr-Hildreth
Canny
Shen-Castan

User defined: Filtering using a custom filter mask that has been defined the under **Edit/Options/Image measurement/Filter**.

Wallis filter: Adaptive contrast compensation with a Wallis filter, whose parameters under can be defined under **Edit/Options/Image measurement/Filter**.

Dilation: Filtering with a morphological dilation of grey value; its structure element must be loaded in advance as a template on the page Correlation. The filter will shrink brighter regions.

Erosion: Filtering with a morphological grey value erosion with a corresponding structure element. The filter will grow brighter regions.

Opening: Filtering with a grey value morphological dilation followed by a grey value erosion with a corresponding structure element.

Closing: Filtering with a morphological grey value erosion followed by a grey value dilation with a corresponding structure element.

Minimum: Filtering with a minimum filter that determines the minimum grey value in a filter window and sets it as the new grey value.

Maximum: Filtering with a maximum filter that determines the maximum grey value in a filter window and sets it as the new grey value.

MinMax: Filtering with a minimum filter followed by a maximum filter.

MaxMin: Filtering with a maximum filter followed by a minimum filter.

Noise: The entered value for statistical noise is added to the color values of the image.

5.11.3 Color

Under *Color*, the color channels of the image can be changed. The selection of the method is done via the *Method* drop-down box.

Implemented methods:

No change: The image does not change

RGB to Grey The RGB input image is converted into a grey value image. The brightness value is determined according to the formula:
g = (R + G + B)/3

RGB to intensity: The RGB input image is converted into a grey value image. The intensity channel of an IHS transformation corresponds to the brightness value.

Grey to RGB: The grey value image (8 bit) is converted into an RGB image (24-bit) with three identical channels.

RGB to red/green/blue: From the RGB input image, the selected color channel will be extracted and stored as grey value image.

RGB to IHS: From the RGB input image three channels for intensity, hue and saturation are generated.

IHS to RGB: From the IHS input image three channels for red, green and blue are generated.

5.11.4 Light fall-off

The natural light fall-off of the image can be corrected. This follows the so-called $\cos^4$ law that describes the intensity drop from the image center to the image edge. The effect is depending only on focal length and image format which optionally be taken from the camera data of the image.

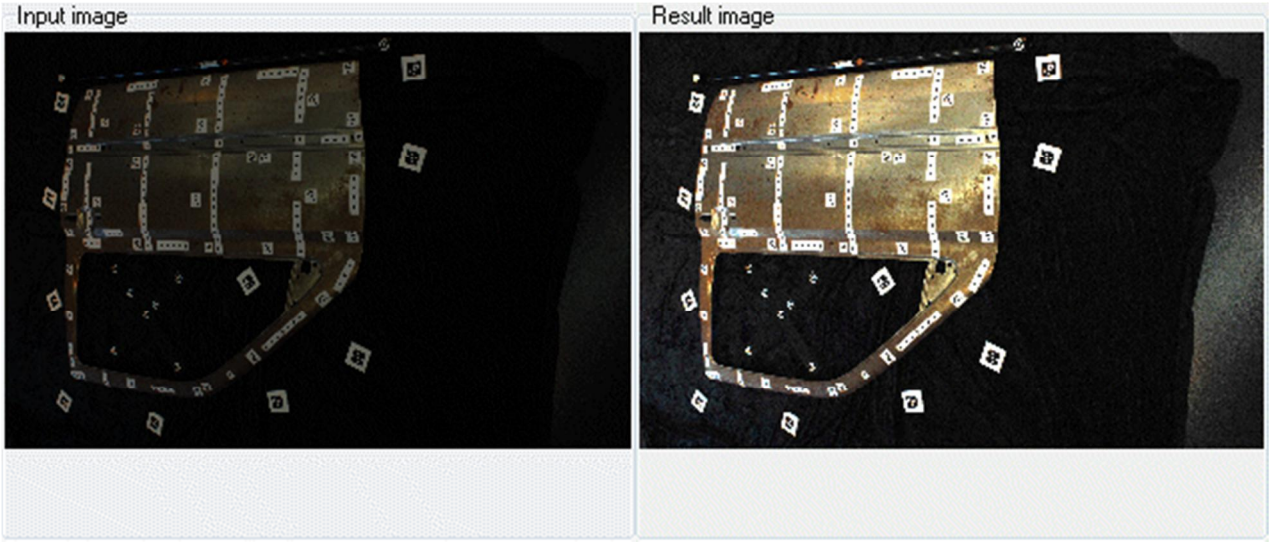


Fig. 58: Correction of light fall-off

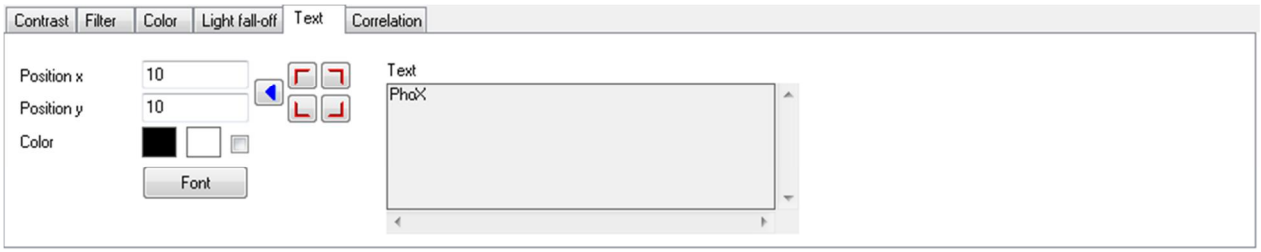
5.11.5 Text

Under *Text*, any text can be written into the image.

XY position Pixel coordinates of the upper-left corner of the text; the position switches place the text in either of the image corners

Color Text color (first box) and background color (second box). If the checkbox is checked, the background color is used, otherwise, the text is drawn transparently. The color can be changed by clicking on the color field.

Text Text box where any text can be entered.



5.11.6 Correlation

Under *Correlation* the input image can be correlated with a pattern image (template) and an output image is generated, in which the grey values represent the correlation coefficient computed at each pixel location. The function is currently only available for grey value images. Large images can cause long computation times.

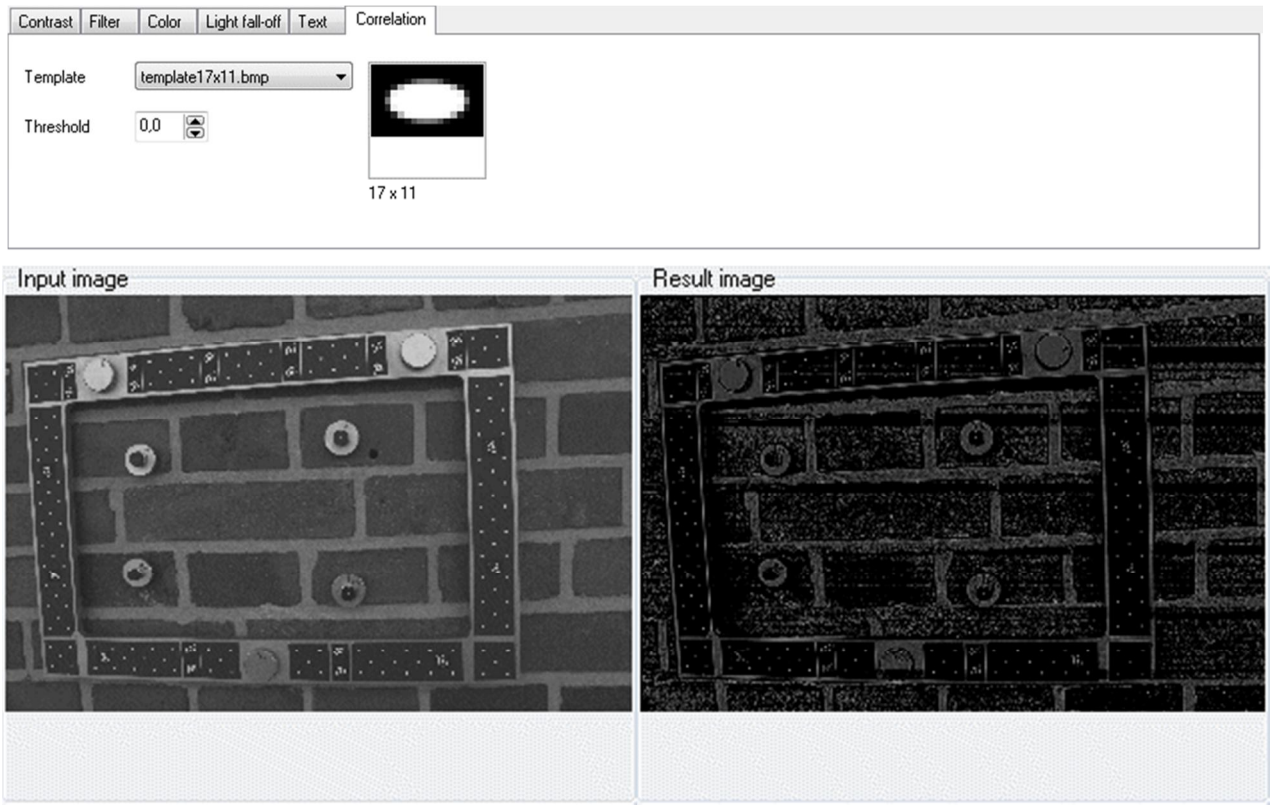


Fig. 59: Image correlation

Template Selection of templates that shall be correlated with the input image. Templates can be managed under **Edit/Options/Image measurement/Template matching**.

Threshold Threshold for the calculated correlation coefficients [0…1]. At a threshold of 0.0, an image is generated where the grey values [0…255] correspond to the interval [0…1]. If a non-zero threshold value is entered, a binary image is created where all pixels exceeding the threshold appear white and all other black.

5.12 Synthetic images

Menu:	Images → Synthetic images
Precondition:	Loaded project

The function **Synthetic images** allows the generation of artificial images by calculating synthetic image data or by combination of existing image data. After calling the function a window appears with various functions with which new images can be calculated.

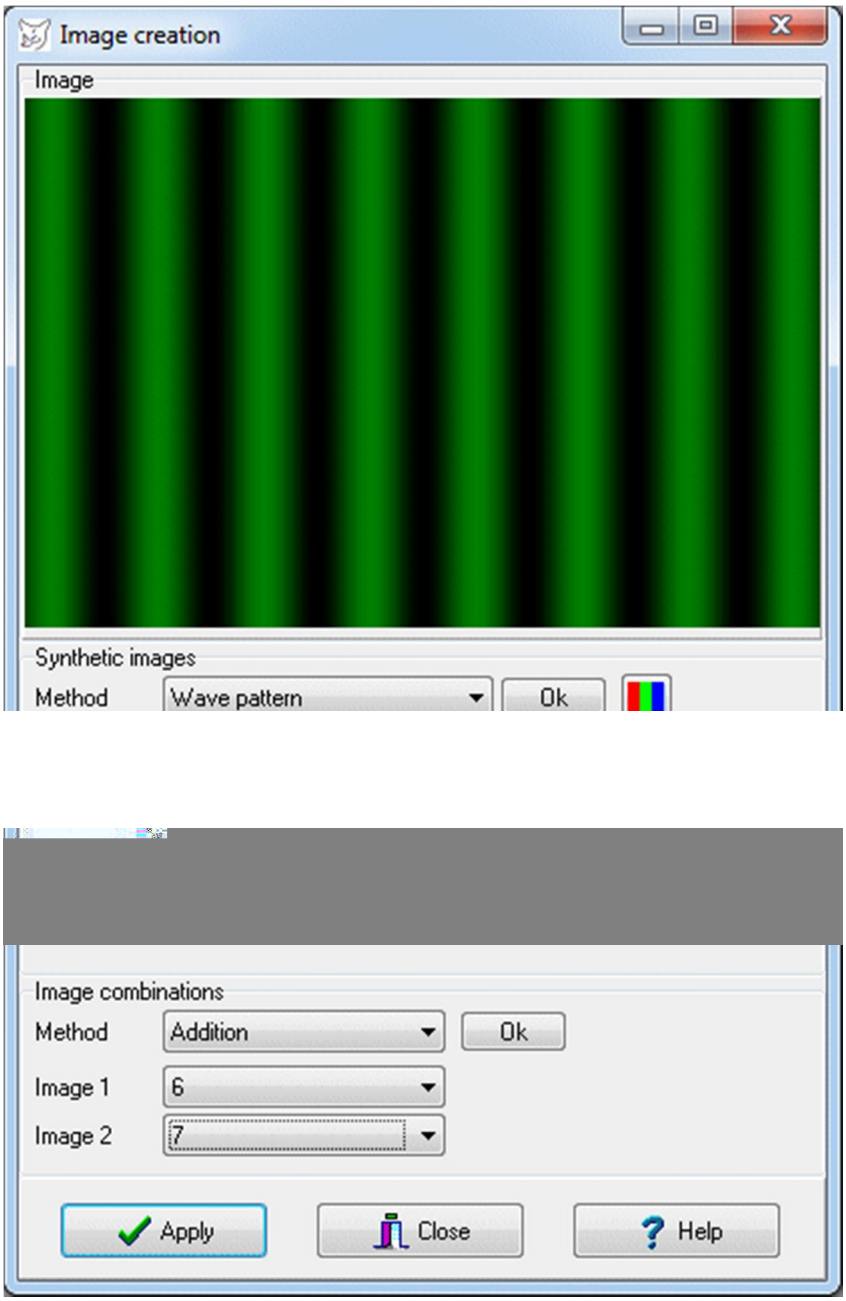


Fig. 60: Window for generation of synthetic images

The computed image appears in the upper image. It can be displayed in 100%by the associated popup menu.

Each performed processing confirmed with OK creates a temporary result image. By pressing the button Apply the image is transmitted into a new image window. If a current image object has been selected at the start of the function, the synthetic image will be created as a new image object with Yes, or it will be assigned to the current image object with No, i.e. the old bitmap of the current image will be replaced by the synthetic image.

5.12.1 Synthetic images

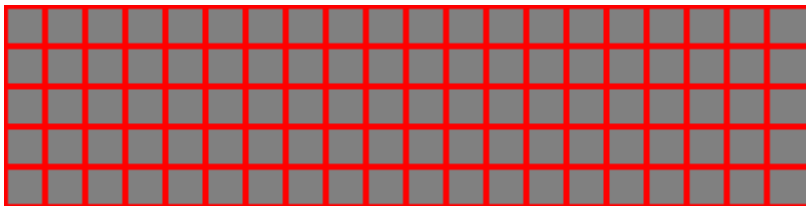
Here methods are offered for generating synthetic images . The selection of the method is done via the *Method* drop-down box. The new image has the entered horizontal and vertical image size. With  either an RGB image or a grey value image is created. The image is generated with OK.

Implemented methods:

Empty image: Creation of an image that is filled with the color selected in the color box.

Empty image with orange color

Grid: Creation of an image with the background color (color box 1) and a grid with a selectable distance of horizontal and vertical grid lines of the specified line width. The grid lines get the color of the color box 2.

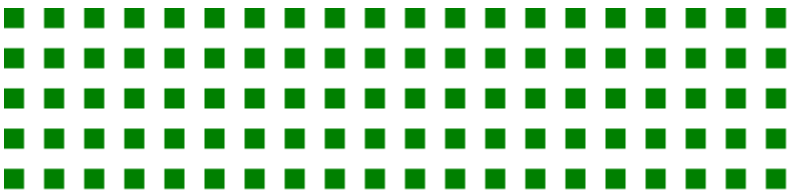


Grid with background grey, color red, 3 line width and distance 32

Chess board: Creation of an image with a selectable number of chessboard fields. The fields have alternating colors of color box 1 and color box 2.

Chess board with white background, blue color and 10 boxes horizontal

Raster: Creation of an image with the background color (color box 1) and a grid with a selectable distance from horizontal and vertical grid points. The grid points have the size and the distance of entered *Size* and the color of color box 2.



Raster with background white, green point and 20 pixel pitch

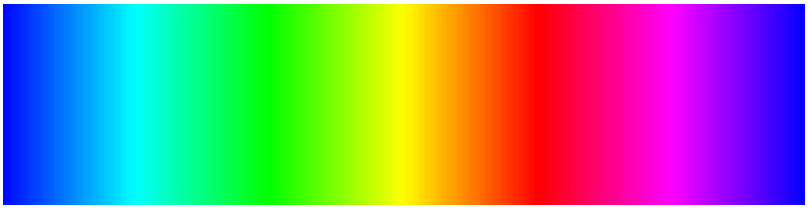
Point grid: Creation of an image with the background color (color box 1) and a grid with selectable intervals in x and y of point patterns of the specified sizes. The grid points have the foreground and background color of the color fields 2 and 3.

Grid with ellipses in orange of size 8 x 4 with a distance of 20 (x) and 30 (y) pixels

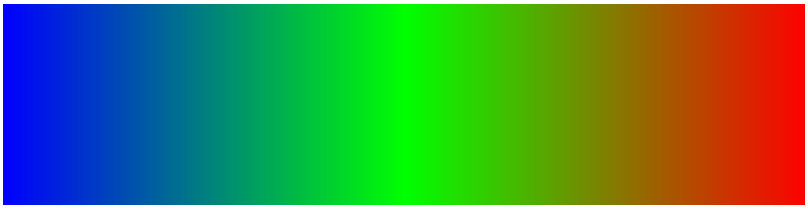
Grey wedge: Creation of an image with grey wedge with n levels between black and white.

Grey wedge (16 Levels)

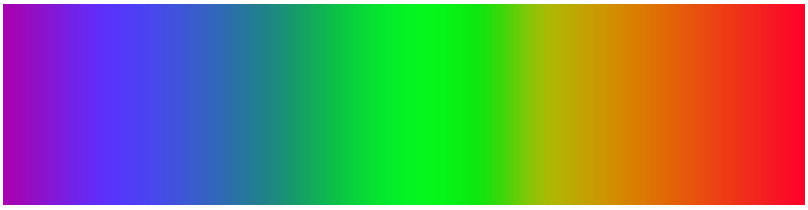
Color scale: Generating a color scale according to selection list.



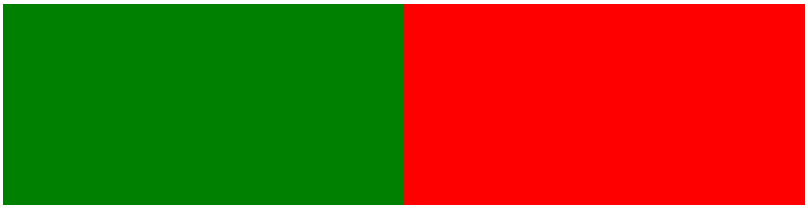
Color circle



Blue-Green-Red



Rainbow



Two colors (Green, Red)

Color interpolation between Green and Red

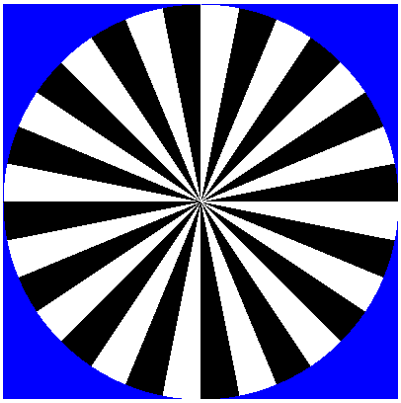
Wave pattern: Generation of vertical strips of width d in the two selected colors. With the switch it can be selected whether the strips form a rectangle or a sine function.

Rectangular wave with a background in black and lines in yellow of width 10

Frequency pattern: Generation of vertical stripes in the two selected colors with continuously decreasing stripe distance from left to right until the rightmost strip has the width 1. With the switch it can be selected whether the strips form a rectangle or a sine function.

Frequency (sine wave) patterns with black and white

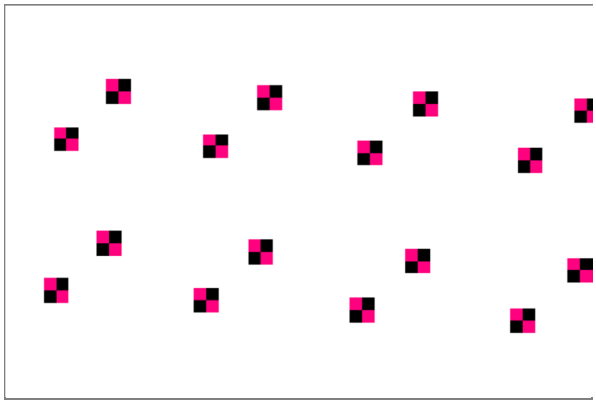
Siemens star: A Siemens star with n sectors in the two selected colors. Areas of the image not belonging to the Siemens star are drawn in the background color.



Siemens star with n = 16, sector colors black and white and background color blue

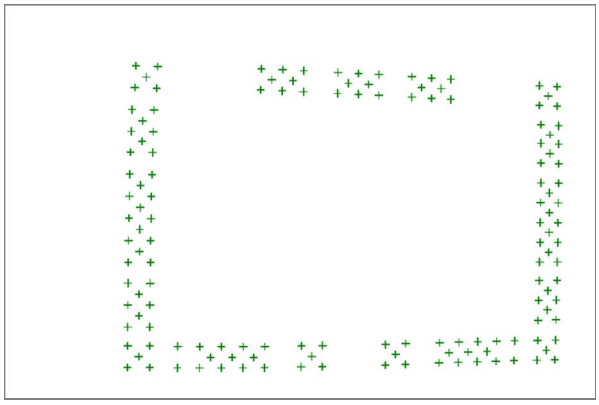
Point patterns: Generation of point-shaped patterns at the image coordinates saved to the current image. It creates initially a blank image with the currently selected size and background color, in that a selectable pattern (e.g. circles or chessboard) in the chosen color is drawn for all stored image points. The size and width of the pattern is

set via the two input fields.



Point image with background color white and chessboard patterns in red and black

Object targets: Point-shaped pattern generation at object coordinates stored for the current object and re-projected into the current image. The size and width of the pattern is set via the two input fields.

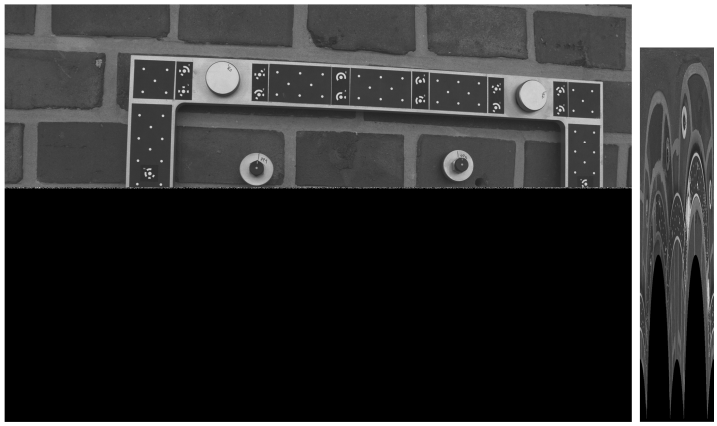


Object points with cross pattern 11 x 3 in green

Polar coordinates: The current image will be converted into polar coordinates, i.e. creates a new image with 360 columns (angle α from 0°to 359°) and *r* rows where *r* is the half image diagonal. The color values of the result image in the map α,*r* correspond to those in the original image at *x*,*y* with

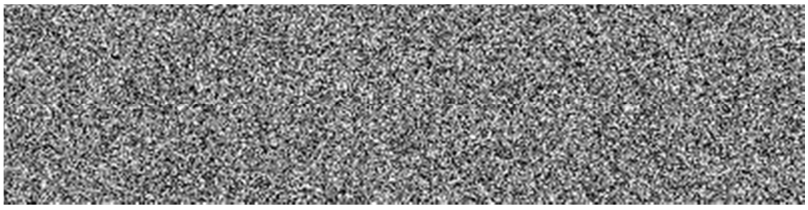
$x = xm + r * \cos(\alpha)$ and $y = ym + r * \sin(\alpha)$,

where *xm*, *ym* is the center of the image of the original image.



Original image (left) and polar image (right)

Noise: Creation of an image with random noise. With it can be selected if a rectangle or a normal distribution of noise is calculated. The color values of the result image have the mean 128 and the standard deviation specified under *Sigma*.



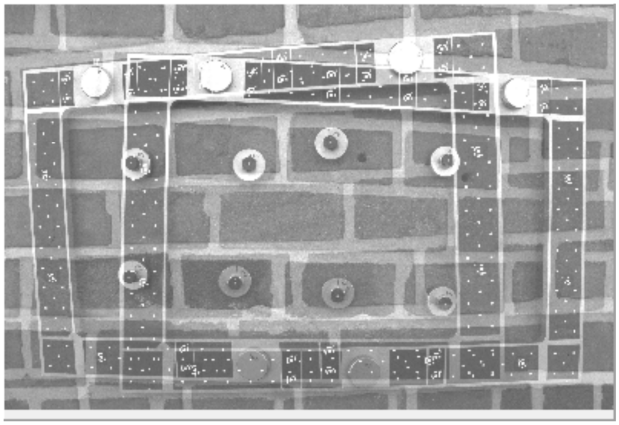
Normally distributed noise with *Sigma* = 64 (grey value image)

5.12.2 Image combinations

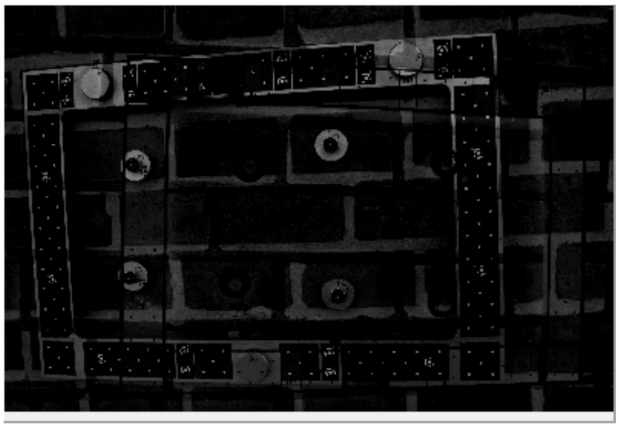
Here methods are offered for the arithmetic combination of two input images. The input images are chosen in the two drop-down boxes and must have the same image size. The selection of the method is done via the *Method* drop-down box. The image is created with OK.

Implemented methods:

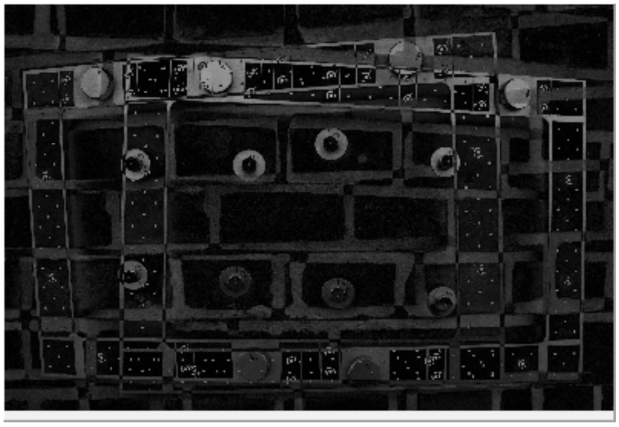
Addition: The color values of both input images are added. On overflow (sum of values > 255) the result is truncated to 255.



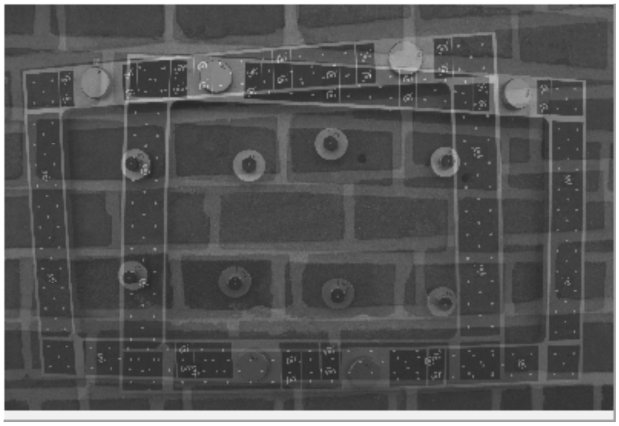
Subtraction: The color values of both input images are subtracted from one another. On overflow (sum of values < 0 or > 255) the result is truncated to the value range [0... 255].



Difference: Calculation of the differences of the two input images.



Average: Calculation of the average values of both input images.



5.13 Contrast slider

Menu:	Images → Contrast slider
Button:	

This function presents four controllers at the bottom of the screen that can control *brightness*, *contrast*, *gamma* value and a *threshold* applied to the current image window. Here, the original image is not changed but only the copy in the image window is adjusted. The contrast change occurs while the slider is moved. For very large images, this operation may take several seconds. Via the popup menu the respective slider is set to the initial position. The button  resets all controls to the default value. With  the current (changed) image window is copied to the original bitmap of the image.

A click to the colour buttons  activates the colour channel for which the contrast modification shall be conducted. The grey button activates all colour channels of the image, the buttons for Red, Green and Blue the corresponding channel only.

If the docking frame Image properties is visible, the look-up table dort calculated for contrast change is displayed in the histogram area.

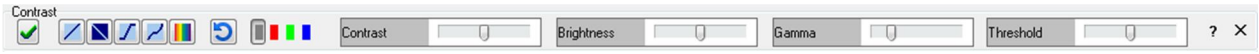


Fig. 61: Sliders for contrast change

Several predefined color palettes can be applied to the image:

- Positive color palette
- Negative color palette
- Histogram stretching
- Histogram equalization
- Rainbow palette (only for RGB images)

6 Menu Measure

The **Measure** menu provides functions for the measurement of image and object points. A point is measured by clicking with the mouse on the desired point. With the key Ins or with function **Zoom window** of the popup menu (right click) the following zoom window opens:

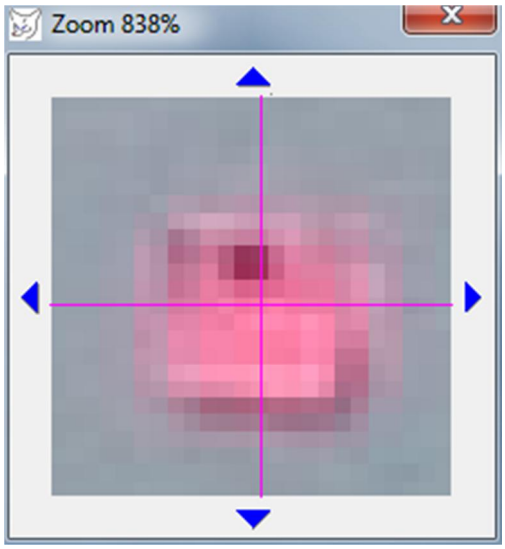


Fig. 62: Zoom window for exact point measurement

The magnification of the zoom window can be set by the mouse wheel or under **Edit/Options/General/Cursor** > *Zoom window*. With the arrow keys of the keyboard or by clicking the blue arrow symbols, the zoom window can be moved.

6.1 Image coordinates

Menu:	Measure → Image coordinates
Button:	
Precondition:	Opened image window

The function **Image coordinates** is used for interactive measurement of image points. They are measured in the unit in which the transformation between pixels and image coordinates is currently defined. For digital images without assigned camera it is by default the unit pixels, for images with camera data, the unit is usually millimeter. Alternatively, image points and ground control point coordinates can be measured in **Measure/Ground control points**.

After starting the function a docking window appears on the right side, in which the image points, measurement method and the measurement itself can be controlled. Under *Method*, different measurement modes can be

selected. The parameters for the point measurement can be set under **Edit/Options/Image measurement/Point measurement**.

Implemented methods:

Manually:	Manual measurement by direct click on the image point with the mouse, if desired within the zoom window.
Process:	Automatic measuring procedure with several consecutive procedures, e.g. centroid measurement, followed by template matching. The desired measurement procedure is defined under **Edit/Options/Image measurement/Measuring process**.
Centroid:	Measurement of a target by centroid calculation of grey values above a threshold within the measurement window.
Ellipse operator:	Measurement of a target by determination of the elliptical outline and calculation of a best-fit ellipse center (star operator).
Template matching:	Measurement of a target by least-squares matching of a template. The template is any (small) grey value image, defined under **Edit/Options/Image measurement/Template matching**.
Cross-correlation:	Measurement of a target by normalized cross-correlation of a template that must be defined as under *Template matching*.
Edge point:	Measures the most prominent edge point at the specified start position according to the settings under **Edit/Options/Image measurement/Point measurement**. Depending on the preset search direction the measuring cursor appears as a horizontal, vertical, or star-shaped cursor.

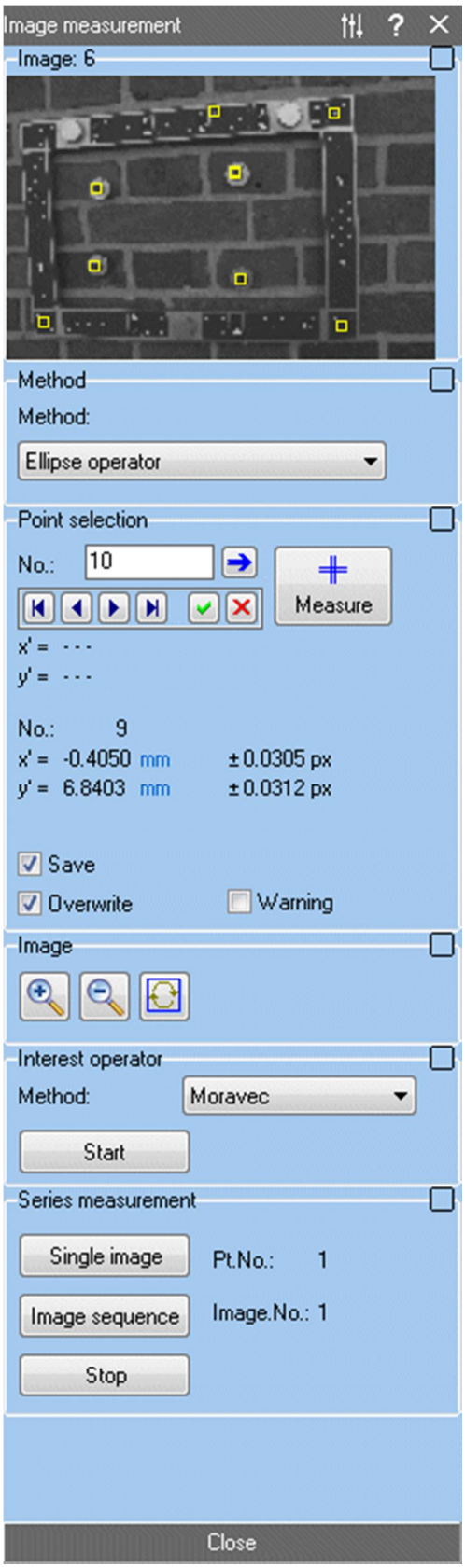


Fig. 63: Docking window for image point measurement

Under Point selection one can navigate through the list of existing image points. The corresponding image coordinates appear below the navigation buttons. selects the next free point number. By pressing the button the selected point is displayed in the image. With the point is deleted.

The button Measure enables the interactive measurement. The button starts to blink and the cursor in the current image switches to the currently set Measurement cursor. The active measuring mode is terminated if the button is pressed again or Esc is pressed. The measured image coordinates are shown below the button Measure. By clicking on the displayed unit the measurements can be displayed in pixel units. After the measurement, the point is automatically stored and the next free point number displayed when the *Save* option is enabled. The existing points are overwritten with the new values, if the *Overwrite* option is set. Otherwise, the points are appended to the already existing image points. If *Warning* is enabled the user has to confirm the storing if a point already exists. Saved points can be listed and managed under **Images/Properties/Image coordinates**.

During the measurement, the user can switch between any image windows.

Under Image the current image window is shown or the window of a point measurement with the existing image measurements is displayed. If the option *Draw measurement result* is selected under **Edit/Options/Image measurement/Measuring process**, details of a point measurement are graphically superimposed (e.g. location of a best-fit ellipse). In the popup menu, the following functions are available:

Original image	Displays the entire original image
Result image	Shows the enlarged image section of the measured point
Original size	Displays the image in the zoom level 100%
Fit	Fits the image to the window
Zoom in	Increases the zoom level of the image
Zoom out	Decreases the zoom level of the image
Image coordinates	Opens the Image properties with the image coordinate list

Under Interest operator distinctive image features can be found. For this purpose the listed methods under **Edit/Options/Image measurement/Interest operators** are available. The detected feature points are stored with the calculated interest values in a separate list to the image object. **Caution:** All interest points of the image will be deleted before executing the function. The detected points are numbered continuously. Maximum 10000 interest points per image can be measured.

Under Series measurement already stored points of the current image (button Single image) or all selected images (button Image sequence) can be re-measured with the selected measurement method. The program automatically sets the points in the image and then starts the selected automatic measurement mode. The function is not intended for manual measurements.

With the button OK the window is closed.

6.2 Image contours

Menu:	Measure → Image contours
Precondition:	Opened image window

The function **Image contours** is used for the measurement of grey scale edges in the image. They are measured in the unit in which the transformation between pixels and image coordinates is currently defined. For digital images without assigned camera it is by default the unit pixels, for images with camera data, the unit is usually millimeters.

Contours are saved as point lists to the image. Each contour has its own name and can contain any number of points. To every contour measurement parameters can be defined individually, e.g. line- or ramp-shaped edge, point spacing, profile length, etc. These parameters should be checked or defined before a measurement.

After starting the function a docking window appears, in which the measurements method and the measurement itself can be controlled. Under *Method*, different measurement modes can be selected.

Implemented methods:

Nodes: After a manual measurement of polygon points (nodes) along a contour, the contour line between the nodes is measured automatically.

Starting point and direction: After a manual measurement of a starting point as well as of a second point, which determines the initial direction of the contour, the contour is automatically followed as long as a termination criterion is reached.

Starting point: After a manual measurement of a starting point, the initial direction of the contour is automatically detected and the contour is automatically followed, until a termination criterion is reached.

Under Contours the contours are managed and measured. The contour list contains a popup menu with the following functions:

New Creates a new contour (alternatively by clicking on the list entry *[new contour]*).

Delete Deletes the selected contour

Properties Opens the *Contours* page of the Image properties, where parameters of the existing contours can be displayed and modified.

The button Points is used for the interactive definition of starting points or polygon nodes, which must be measured according to the above selected *Method*. The button is blinking in active mode.

With Measure the measurement of a contour is enabled. Automatic contour tracking continues until a termination criterion is reached. This can happen due to the following reasons:

End reached: The measurement reaches the defined end node of the contour (only in mode *Nodes*).

Start reached: The measurement reaches the defined starting point of the contour, i.e. the contour is a closed polygon.

Abortion: The measurement was canceled because no plausible contour point could be measured.

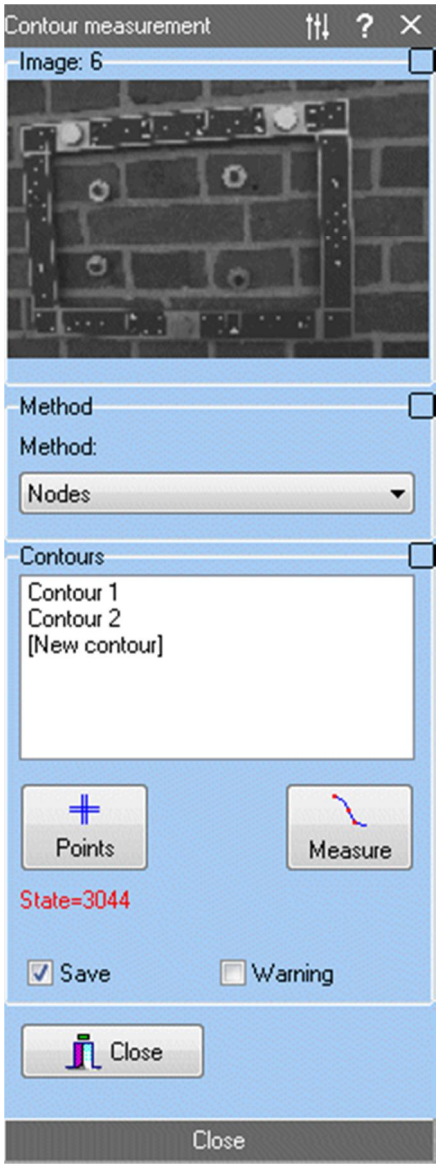


Fig. 64: Docking window for the contour measurement

6.3 Ground control points

Menu:	Measure → Ground control points
Precondition:	Opened image window and activated object

The function **Ground control points** is used for interactive measurement of image positions of ground control points. They are measured in the unit in which the transformation between pixels and image coordinates is currently defined. For digital images without assigned camera it is by default the unit pixels, for images with camera data, the unit is usually millimeter.

The control points are saved for the currently selected object. If control point coordinates already exist, they are displayed here.

After starting the function a docking window appears on the right side, in which the image points, object points and the measurement itself can be controlled.

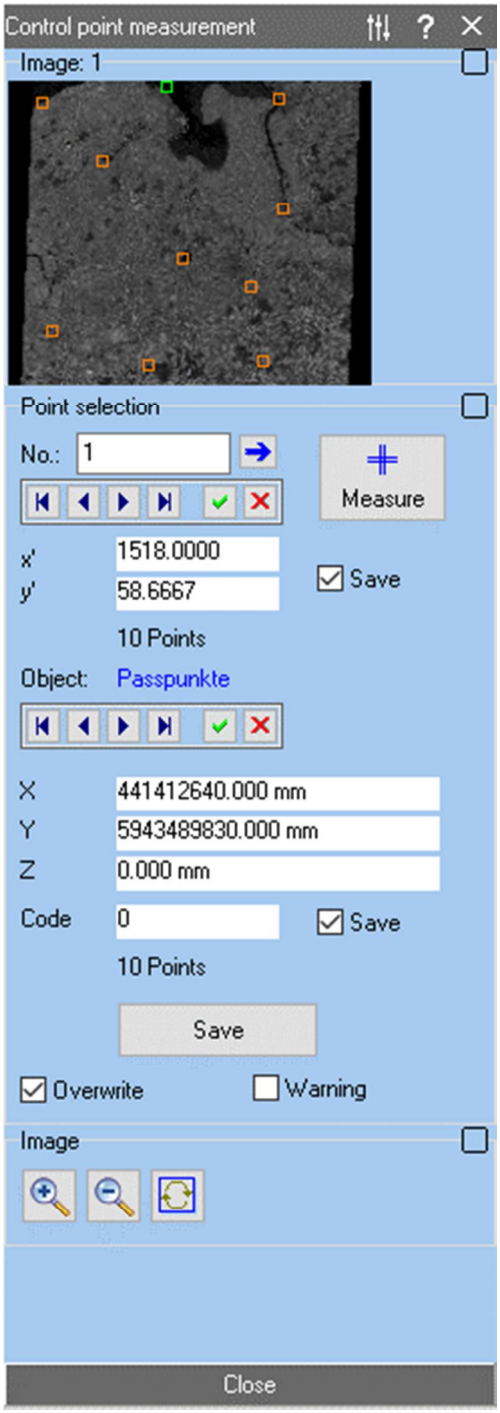


Fig. 65: Docking window for ground control point measurement

Under Point selection one can navigate through the list of existing image points. The corresponding image coordinates appear below the navigation buttons. selects the next free point number. By pressing the button

the selected point is displayed in the image. With the point is deleted. There is a separate navigation bar for image and object points.

The button Measure enables the interactive measurement. The button starts to blink and the cursor in the current image switches to the currently set Measurement cursor. The active measuring mode is terminated if the button is pressed again or Esc is pressed. During the measurement, the user can switch between any image windows. The measured image coordinates are shown below the button Measure. The point measured in the image is only saved when the Save button is pressed.

Use the Save button to save the displayed image and control point coordinates. The *Save* check boxes enable the storage of the respected coordinates. If the *Overwrite* option is set, existing points are overwritten with the new measurement values. Otherwise the points are appended to the already existing points. If *Warning* is activated, the user must confirm the saving if a point already exists. Stored image points can be managed under **Images/Properties/Image coordinates**, stored object coordinates under **Objects/Object properties/Object coordinates**.

Under Image the current image window is shown or the window of a point measurement with the existing image measurements is displayed. In the popup menu, the following functions are available:

Original image	Displays the entire original image
Fit	Fits the image to the window
Zoom in	Increases the zoom level of the image
Zoom out	Decreases the zoom level of the image
Image coordinates	Opens the Image properties with the image coordinate list

With the and buttons the image window can be zoomed if necessary. Press to redraw the graphic in the image window.

6.4 Object coordinates

Menu:	Measure → Object coordinates
Button:	
Precondition:	Opened image window

The function **Object coordinates** serves to measure 3D object points. The function can only be executed if the interior and exterior orientations of the corresponding images are given and their bitmaps are loaded.

Under Object the input and output object is defined. The input object is used for the setting of existing object points when these should be selected via the navigation buttons. The output object is used to store the

measured coordinates. By typing a new name into the selection field and confirmation with , a new output object is created. Input and output object can be identical, then existing points will be overwritten by newly measured points.

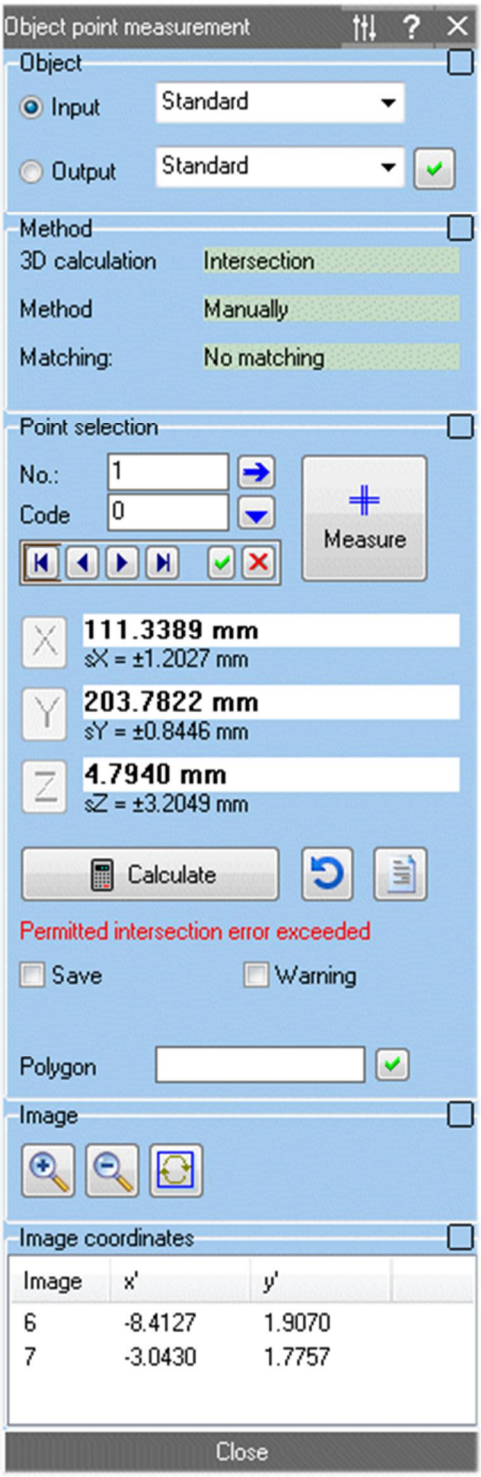


Fig. 66: Docking windows for object point measurement

The 3D calculation methods as well as the type of image measurement must be set before the measurement of object points.

Implemented Methods to *3D calculation*:

Intersection: Spatial forward intersection with the measured image coordinates from at least two images. The number of images is arbitrary. The measurement will be activated with button Measure. When a point was measured in one image, the point is displayed in the list of image coordinates. If the point has been measured in at least two images, the forward intersection is calculated automatically and the resulting 3D coordinates along with the standard deviation are displayed. With *py'* the mean standard deviation resp. y-parallaxe reprojected into image space is given. The corresponding epipolar lines can appear if the appropriate option for epipolar lines has been set under **Edit/Options/General/Graphics**. With the Back key the image window can be centered on the epipolar line if it otherwise should be outside of the window.

3D floating mark: A measuring mark appears according to the currently displayed XYZ position in all open images. The buttons X, Y and Z are enabled. By clicking on the buttons with the left mouse button held, the corresponding coordinates increases by an increment and decreases with the right mouse button. The increments in object space DX =, and so on, will be displayed below the 3D coordinates and can be set clicking on or by calling the page **Edit/Options/Compilation/3D calculation**. If the active measuring mode is activated with Measure, the 3D floating mark can be moved three-dimensionally by mouse movements and mouse wheel. Under **Edit/Options/General/Cursor** the sensitivity of the mouse movement can be set. The mark can be moved with the predetermined increments using the arrow keys on the keyboard. Arrow left/right: X direction; Arrow up/down: Y-direction; Shift+Arrow up/down: Z-direction. The set point is stored, if the button Enter is pressed. The active measuring mode can be terminated with Esc.

Monoplotting DTM: In this mode, the 3D coordinates are measured by intersecting an image ray with a digital terrain model (DTM). The measurement will be activated by the button Measure. When a point is measured in one image, the 3D coordinates are calculated. Prerequisite is the presence of a regularly built digital surface model (point cloud) that must be loaded to the current object.

Monoplotting TIN: The 3D coordinates are formed by intersecting an image ray with a TIN (triangular meshing). The measurement will be activated by the button Measure. When a point is measured in one image, the 3D coordinates are calculated. Prerequisite is the existence of a triangle list, which must be stored to the current object. The creation of a TIN can be done under **Objects/Meshing**.

Implemented *Methods* for image measurement:

Manually: A point is measured by manually clicking with the mouse. The precision of the measurement can be increased if the image is zoomed or the zoom window is used.

Process: Automatic measuring process with several consecutive procedures, e.g. centroid measurement follows by template matching. The desired measurement procedure is set under **Edit/Options/Image measurement/Measuring process**.

Centroid: Measurement of a target by centroid calculation of grey values above a threshold within the measurement window.

Ellipse operator: Measurement of a target by determination of the elliptical outline and calculation of a best-fit ellipse center.

Template matching: Measurement of a target by least-squares matching of a template. The template is any (small) grey value image, defined under **Edit/Options/Image measurement/Template matching**.

Cross-correlation: Measurement of a target by normalized cross-correlation of a template that must be defined as under *Template matching*.

Edge point: Measures the most prominent edge point at the specified start position according to the settings under **Edit/Options/Image measurement/Point measurement**. Depending on the preset search direction the measuring cursor appears as a horizontal, vertical, or star-shaped cursor.

Implemented methods for *Matching*: (only in mode *Intersection*)

No matching: No procedure is uses to match the exact assignment of corresponding points.

Stereo correlation: The area of the point clicked in the first image is used as a reference window for a cross-correlation, whereby the area of the point clicked in the second image is used as the search window. The procedure locates the point of highest correlation automatically and replaces the point measurement in the second image. After successful correlation the measuring cursor in the second picture is placed on the new point. The correlation parameters can be adjusted under **Edit/Options/Image measurement/Correlation**.

LSM correlation: Instead of the cross-correlation a least-squares matching (LSM) is used. Not yet implemented.

Under Point selection the first point number to be measured is set, where the point selection refers to the activated *Input* or *Output* object. The button represents the next free point number. With button a predefined point code can be chosen. By pressing the button the selected point in the image is displayed. With the switch the point is deleted from the list. The navigation buttons iterate through the list of existing points.

Under X, Y, Z the stored or calculated 3D coordinates appear to the currently selected point. Depending on the measuring method, the individual standard deviations are shown below. If new coordinates are entered in the input fields, the cursor jumps to the corresponding image position in all open images.

The button Measure enables the interactive measurement. The button starts to blink and the cursor in the current image switches to the measuring cursor. The active measuring mode is terminated if the button is pressed again or Esc is pressed. The measured image coordinates are displayed in the list of image coordinates.

If the *Save* option is enabled, the measured point is automatically saved after the measurement and the next free point number is shown. If *Warning* is active, the user must confirm saving if the point already exists. The option *Image coordinates* serves for storing the measured image coordinates of each 3D point.

With the option *Epipolar* the movement of the measuring cursor is forced to a band along the superimposed epipolar lines. The width of this band can be set under **Edit/Options/General/Cursor**. This feature is currently disabled.

Under *Polygon*, the name of a polygon to contain all currently measured 3D point series can be specified. When the measurement of a polygon shall be terminated, a new name must be entered or the button must be pressed.

The button Calculate performs the forward intersection of the measured image coordinates (again). The button deletes all measured image coordinates.

Under Image the current image window can be enlarged, reduced, or repainted.

During the measurement, the user can switch between any open image windows. A click into the respective image leads immediately to an image measurement, i.e. you must click on the edge of the window, if only the active window shall be changed.

6.5 Model coordinates

Menu:	Measure → Model coordinates
Precondition:	Existing stereo model with bitmaps

The function **Model coordinates** serves to measure the 3D model coordinates in a relatively oriented stereo model. The function can only be executed if a stereo model with two defined images is enabled. The aim is the acquisition of homologous points in the coordinate system of the model. The measurement is carried out basically in the same way as the Measurement of object coordinates.

Fig. 67: Docking windows for model coordinate measurement

After starting the function, the two images of the selected stereo model are displayed in left and right image windows.

Appropriate model coordinates are stored under the selected stereo model. They can be displayed and modified under **Orientation/Stereo models**. There, the model coordinates can be converted into a regular 3D object.

6.6 Stereo

Menu:	Measure→ Stereo
Precondition:	Existing stereo model with bitmaps and existing object

The **Stereo** function is used for stereoscopic measurement of 3D object coordinates in an oriented stereo model. The function can only be executed if a stereo model with two defined images is activated. The 3D measurement is performed using the spatial floating mark principle. The stereo image is displayed in anaglyph form. Anaglyph glasses adapted to the colour model described below are required for measurement. The measurement mode is limited to 2½D evaluations, i.e. the XY plane must be approximately parallel to the image planes. The function is still being tested.

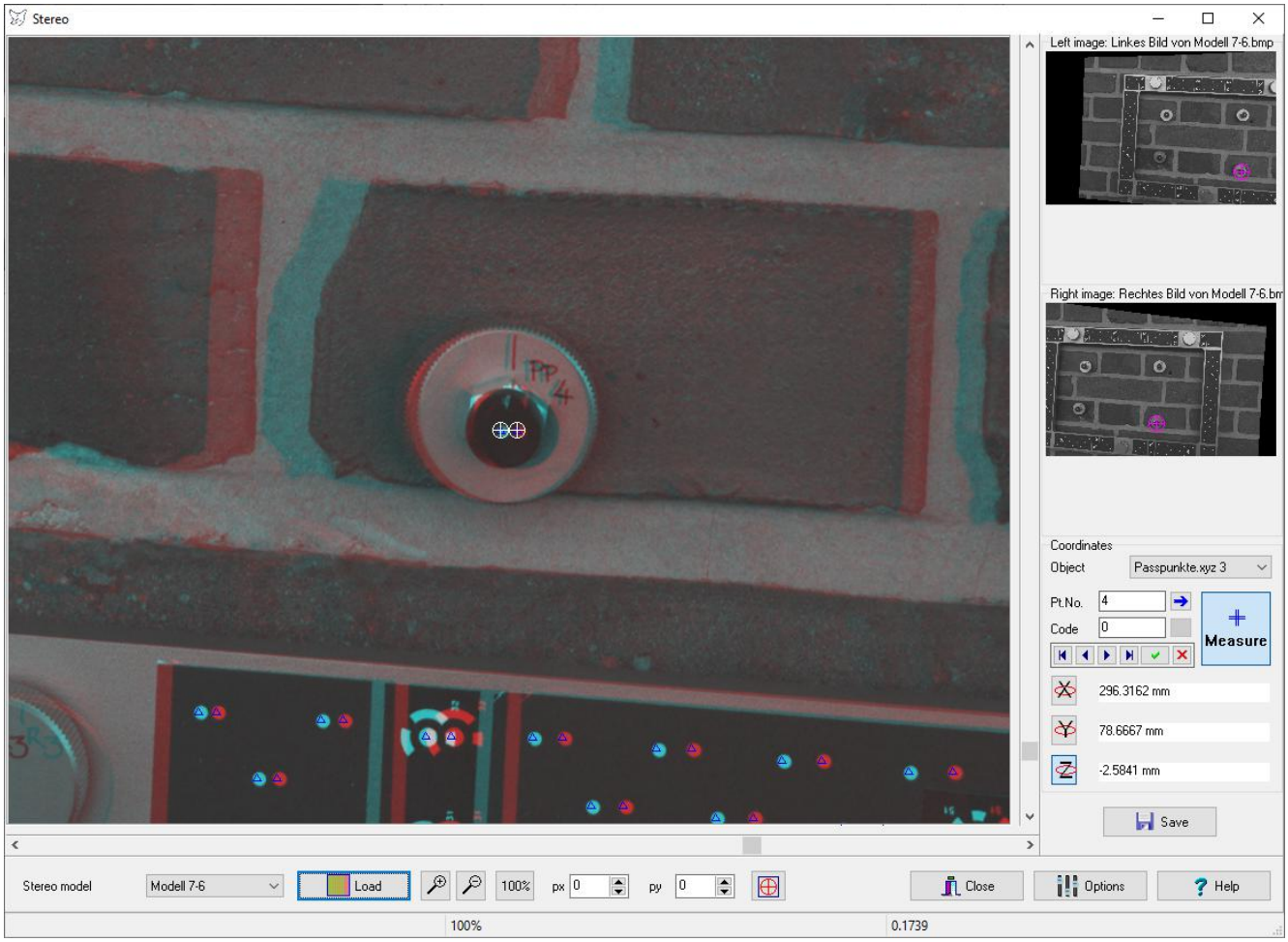


Abb. 68: Stereo measurement

The stereo model to be evaluated is selected under Stereo model. It is recommended to use an absolutely oriented stereo model with rectified normal images. The corresponding images are displayed in the overview images shown on the right. Load calculates and displays the anaglyph image. For very large input images (more than 300 MB) the resolution of the anaglyph image will be reduced by a factor of 2 or more. The colouring depends on the colour mode that can be selected under **Edit/Options/3D calculation/Stereo**. A suitable x-parallax between both images is calculated from the base and distance of the images to the object. Horizontal (x) and vertical (y) parallaxes can be adjusted via the input fields *px* and *py* if required. The image can be

enlarged or reduced using the magnifying glass symbols. Clicking in an overview image centres the stereo image at the desired position.

The current object is selected under Coordinates. Existing object points can be selected or edited via the navigation bars. After selecting a point, the stereo image is centred on the point.

The **Measure** button starts the measurement and displays a stereoscopic floating mark at the current XYZ position. The shape and size of the floating mark can be changed under **Edit/Options/General/Cursor**. The colour of the measurement mark depends on the selected cursor mode, which can be selected under **Edit/Options/3D calculation/Stereo**. The switches X, Y and Z determine which coordinate direction corresponds to the depth (distance) (default: Z). The depth measurement (e.g. in Z) is done by moving the scroll wheel of the mouse, whereby the step size can be adjusted by simultaneously pressing the keys Ctrl, Shift or Alt. The position coordinates (e.g. XY) are changed by moving the mouse, whereby one of the keys Ctrl, Shift or Alt must be pressed here. The correct 3D position results when the measurement mark "sits on", i.e. that it stereoscopically gives the impression of sitting exactly on the surface point. This is equivalent to the two displayed measurement marks being set on the same homologous point in both images. If the measured 3D point is to be saved with the currently displayed point number, this is done by pressing the Enter key or the Save button. The next free point number is then displayed.

If the measuring mode is active, a mouse click in the stereo image causes the floating mark to be placed approximately at this position. If the measuring mode is not active, the closest object point to the mouse position is searched for.

During measurement the floating mark can be set automatically using the vertical line locus method (VLL). The floating mark is moved in a range from Zmin to Zmax in incremental steps deltaZ. At each corresponding position the two related image patches are correlated. deltaZ is equal to the smallest step width of the floating mark. This parameter is calculated automatically in the order of the ground sample distance GSD. automatically. The Z value with highest correlation coefficient will be used as new floating mark position. The size of the correlation window is defined under **Edit/Options/Image measurement/Correlation** by the parameters of the *reference window* (e.g.. 11 x 11 pixel). The number of interval steps is equal to the size of the *search window* in x (e.g. 21). The minimal required correlation coefficient is defined by *threshold*.

The following short-cuts are available:

F1	Help
+	Zoom in
-	Zoom out
C	Set floating mark automatically (VLL)
Enter	Save current 3D coordinates

6.7 Point cloud

Menu:	Measure → Point cloud
Precondition:	Opened image window and activated object

The function **Point cloud** is designed to measure 3D surfaces. These are organized in the form of regular digital surface models or in freely structured point clouds. For measurement a docking window will be opened for the selection of measurement methods, input images, etc. The measurement of single object points can only be conducted under **Measure/Object coordinates**. Under Method measurement procedures and measurement methods are set. After entering the desired settings all points are measured with the button Start. A current measurement can be terminated using the button Esc. The measured points are automatically saved under the object entered in the field *Target object*.

Methods for *3D calculation* are:

Intersection: The measurement is carried out starting from the given image point of the first image. Approximate values of the image coordinates of the other images are calculated using the most recently calculated XYZ value and the corresponding point is determined manually or automatically (by selected matching method). The 3D coordinates of the object point are calculated by spatial forward intersection. Not yet implemented.

3D floating mark: The object point calculation is performed via the process of vertical line locus (VLL). Based on approximate coordinates the Z value is changed successively, until the point sits on the surface. Not yet implemented.

Monoplotting DTM: In this mode, the 3D coordinates are formed by intersecting an image ray with a digital terrain model (DTM). Prerequisite is the presence of a regularly built digital surface model (point cloud) that must be loaded to the current object. Not yet implemented.

Monoplotting TIN: The 3D coordinates are formed by intersecting an image ray with a TIN (triangulation, meshing). Prerequisite is the existence of a triangle list, which must be stored to the current object.

Under Images the images involved in the measurement are selected by activating the check box. The topmost selected image is used for procedures on the basis of monoplotting here.

Under Dimensions the area for the measured surface points should be set. In mode *Image* the definition of the measuring area relates to the pixel coordinates of the first image, i.e. the measurement program iterates through all pixels in the selected area of the image and determines the corresponding coordinates of the object. In contrast, in mode *Object* a rectangular area is defined in object space coordinates. The corner coordinates of the measuring area are defined by input of *X* and *Y* (*Min*/*Max*). The distance between the measuring points to each other is entered under *DeltaX* and *DeltaY*. This results in a corresponding maximum number of measurement points identified in the line below.

Target object defines the object where the measured point cloud is stored. If a name of a non-existent object is entered here, it will be generated prior to the measurement. If an existing object is set, the measurement will overwrite an existing point cloud.

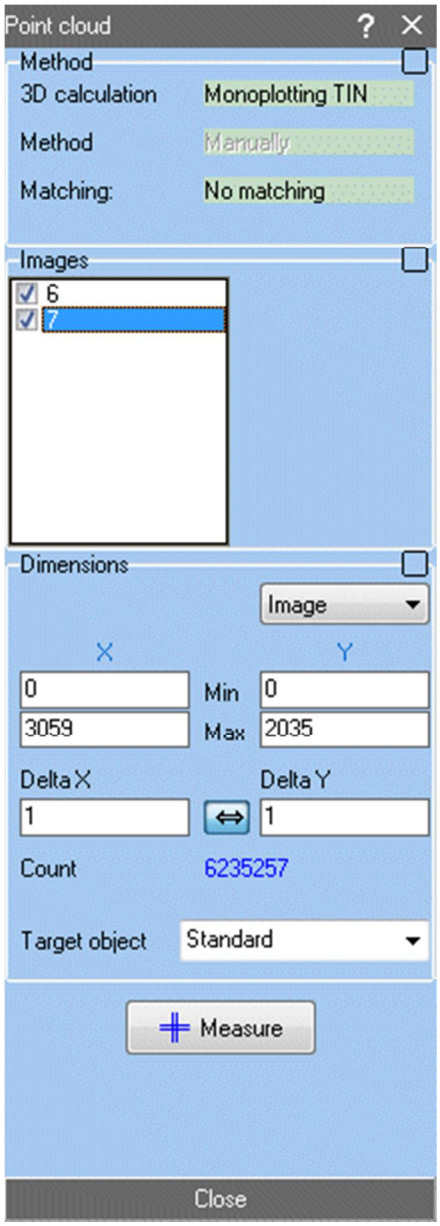


Fig. 69: Docking window for measurement of surfaces

6.8 Spatial intersection

Menu:	Measure → Spatial intersection
Precondition:	Min. 2 existing image objects

The function **Spatial intersection** is used for the calculation of a 3D spatial forward intersection with already existing image coordinates. A window will be opened to select the input images and image points. The interactive measurement of single object points can only be carried out under **Measure/Object coordinates**.

Under Image selection the involved images are selected. Either *all images* can be used or a specific selection of images can be defined with the button [...]. At least two images must be selected.

Under Point selection the image points to be used for the calculation are selected. Either *all points* can be used or a specific selection of points can be defined with the button [...].

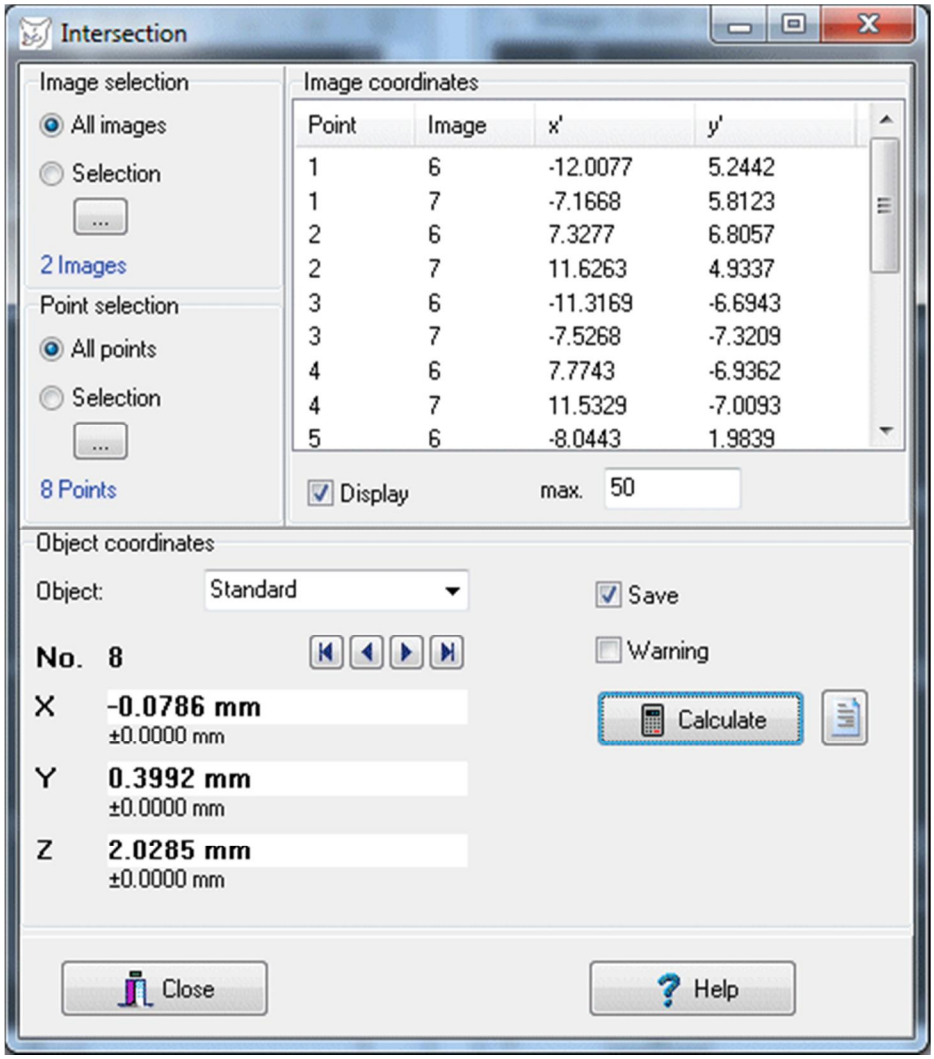


Fig. 70: Docking window to calculate forward intersections

Under Image coordinates a list of the presently stored image coordinates of the selected points appears if the option *Display* is enabled. The number of displayed points can be restricted by the entered max. value because

a very large amount of points leads to a delay for listing. Only image points which identical point numbers in the selected images are displayed.

The button Calculate starts the computation of forward intersections for all selected points. The computed 3D coordinates and their standard deviations are reported. With *py'* the mean standard deviation resp. y-parallaxe reprojected into image space is given. The point is stored under the object defined at *Object*. If no name is entered here, no points are saved. If a non-existent object is specified here, it will be created. If the *Save* option is disabled, no 3D points are stored at all. If *Warning* is enabled, the override of existing points must be confirmed.

Using the navigation buttons the individual points of the above point list are selected and their 3D coordinates are computed immediately, but not saved.

6.9 Interior orientation

Menu:	Measure → Interior orientation
Precondition:	Opened image window with assigned camera

The function **Interior orientation** serves to measure the fiducial marks or réseau points in a scanned analog image. Thus the transformation between the pixel coordinates and the metric image or camera coordinates of the image is calculated. The nominal coordinates of the fiducial marks are stored in the camera file. The function can run only when a camera is associated to the image and this camera has at least two fiducial marks.

A docking window, in which the measurement of image data is performed, will appear after the call of the function.

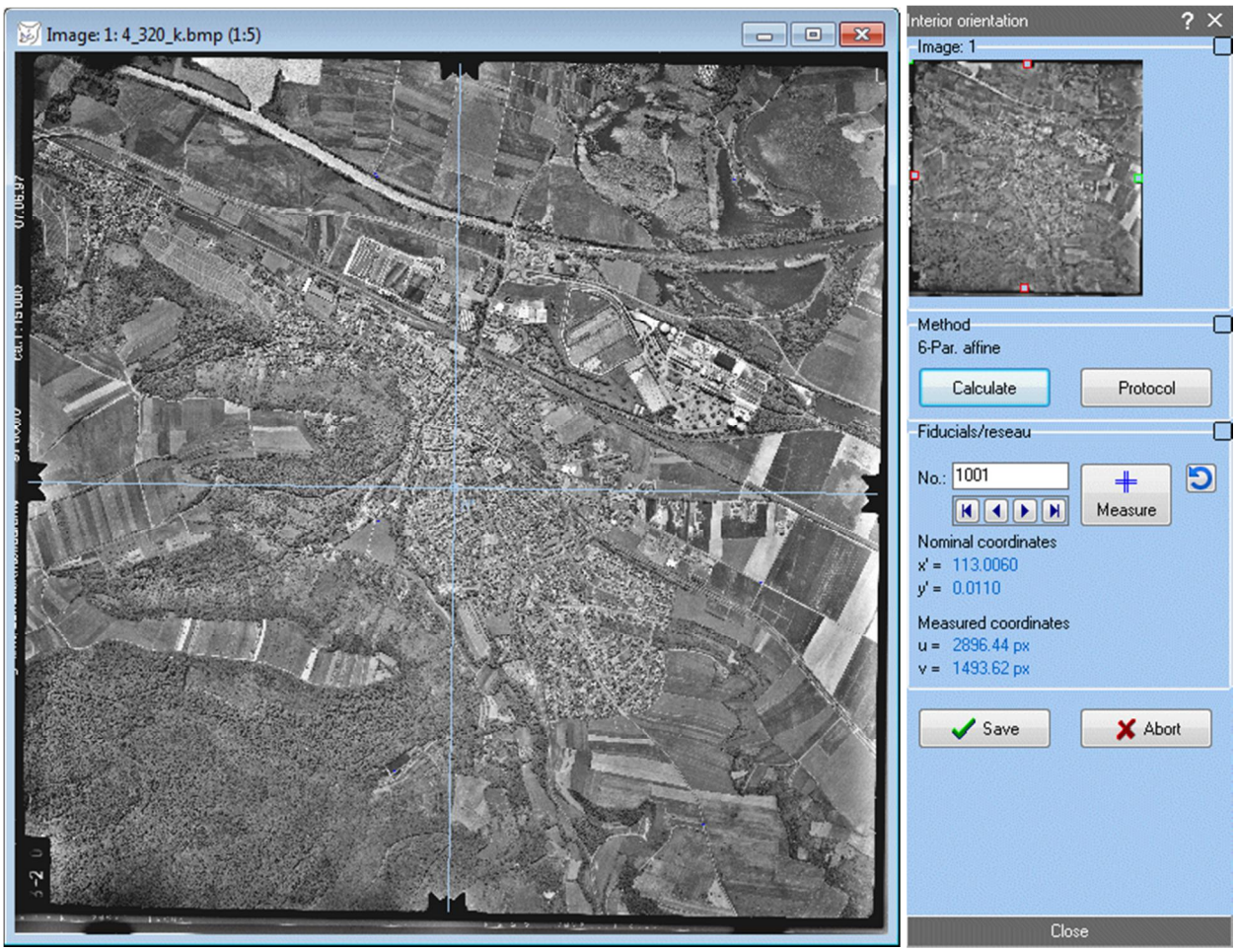


Fig. 71: Docking window (right) and activated image window (left) to measure the interior orientation

Under Image the overview image of the current image appears. Here the corresponding location in the image window will appear by clicking with the mouse, for example to search for the next fiducial mark.

Under Method the calculation of transformation can be started with Calculate and the result of the calculation can be displayed with Output log. The coordinate transformation is used to convert between pixel and image coordinates as being set in the camera file (usually a 6 parameter or affine transformation).

Under Fiducials/reseau the pointwise measurement of reference points is performed. The name, number, and order of the points are set according to the camera data and cannot be changed here. With the navigation buttons, the desired point is selected. With the button Measure the measurement of the indicated point is activated. A measurement cursor appears in the associated image to measure the desired point (e.g. a fiducial mark). After clicking on the point, the corresponding pixel coordinates (coordinates u, v) are stored and the next point is selected. Pressing the button Measure again terminates the active measuring mode. The button deletes all measured fiducial coordinates and resets the program to the first point.

After measurement of all points the transformation is calculated with Calculate. With OK the transformation is assigned to the image, with Cancel the result is discarded.

During the measurement of an image this may not be deleted, closed, or changed. Also it is not permitted to switch between image windows.

6.10 Image scale

Menu:	Measure → Image scale
Precondition:	Opened image window with assigned camera

The function **Image scale** serves to measure the image scale an image by a measured distance in the image and a given corresponding distance in object space. The function can run only when a camera is associated to the image, i.e. a metric image coordinate system must be given.

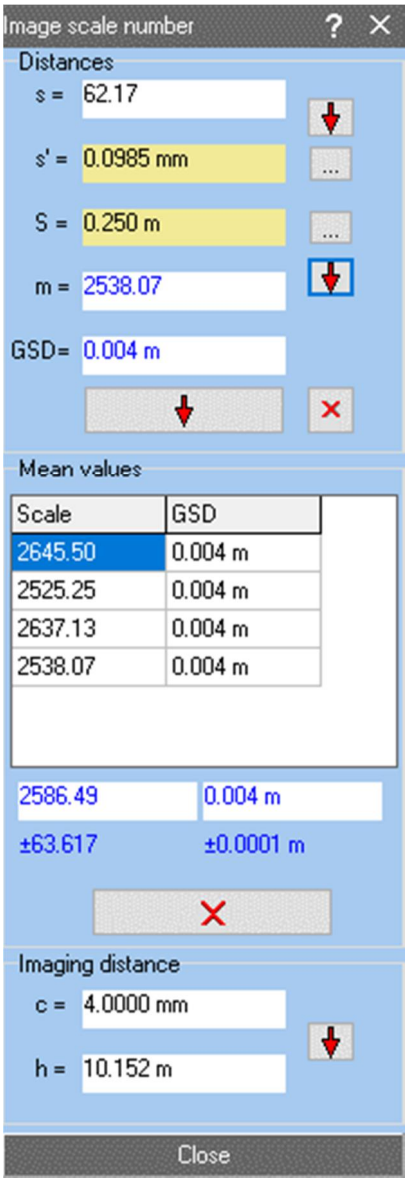


Fig. 72: Docking window for the measurement of image scale

A docking window, in which the measurement of image distances is performed, will appear after the call of the function. For that purpose it is recommended to select the line cursor so that measured distances are visible. After clicking on the second image point (endpoint of distance) the distance in pixel coordinates *s* and in metric image coordinates *s'* will be displayed. Optionally a distance in pixel units can be transformed into the metric distance with top button  . The corresponding object distance *S* must be entered manually.

From the distances the resulting image scale *m* = *S* / *s'* is calculated either automatically or with second button  . In addition, the current ground sample distance (*GSD*) is calculated using the physical pixel size of the camera resp. camera.

With the middle button  the current measurement results for *m* and *GSD* are transferred into the bottom table Mean values which calculates the mean values and standard deviations continuously. Button deletes the last entry from the table, button  deletes the complete table.

Under Imaging distance the camera constant or focal length *c* can be converted with the current image scale into the corresponding imaging distance (flight altitude) *h*. For *c* any positive values can be entered here.

7 Menu Orientation

The menu **Orientation** provides functions to calculate the exterior or relative orientation.

7.1 Resection

Menu:	Orientation → Resection
Precondition:	Existing image object

The function **Resection** is used for calculating the exterior orientation of the image. This function requires a 3D object with a minimal number of spatial control points, as well as the previously measured corresponding image coordinates.

The image to be oriented can be selected under Image. An overview image appears below if a bitmap is loaded to the selected image. The existing (red) and currently selected image points (green) will be displayed. For single image orientation, the image points should be distributed equally over the image. If all selected points are close to a joint straight line, the calculation process will be canceled or it will lead to unsafe results.

A calculation type can be selected under Method. Available options are currently:

Space resection	Space resection requires a minimum of four points to determine the exterior orientation through least-squares adjustment. Since the applied collinearity equations are not linear, the procedure needs start values that can be calculated with the button Initial values.
Direct linear transformation	The DLT requires at least six spatially distributed points, but no initial values. The procedure determines five parameters of interior orientation and six parameters of exterior orientation.
Manual input	The six parameters of exterior orientation which are entered in the field Result, are assigned to the current image.

Under Control points the requested *image*, the *object* and the image and object points, which will be used for calculation, are selected. If a sufficient number of identical points have been selected according to the particular method, the calculation of approximation values (for space resection) can be execute with Initial values, and the calculation of the final exterior orientation with Calculate under Calculation. If the check box  is active, the initial values are calculated automatically, otherwise the displayed values are used as initial values. With  , a

calculation log file can be displayed that is stored in file resection.txt. The button resets the displayed parameters to the exterior orientation stored to the current image.

Under Result the six parameters of exterior orientation together with their standard deviations are displayed. For the DLT standard deviations are currently not calculated. The orientation parameters can also be edited here and finally saved with Save. The image residuals calculated in the adjustment are stored with the original image coordinates (sigma values).

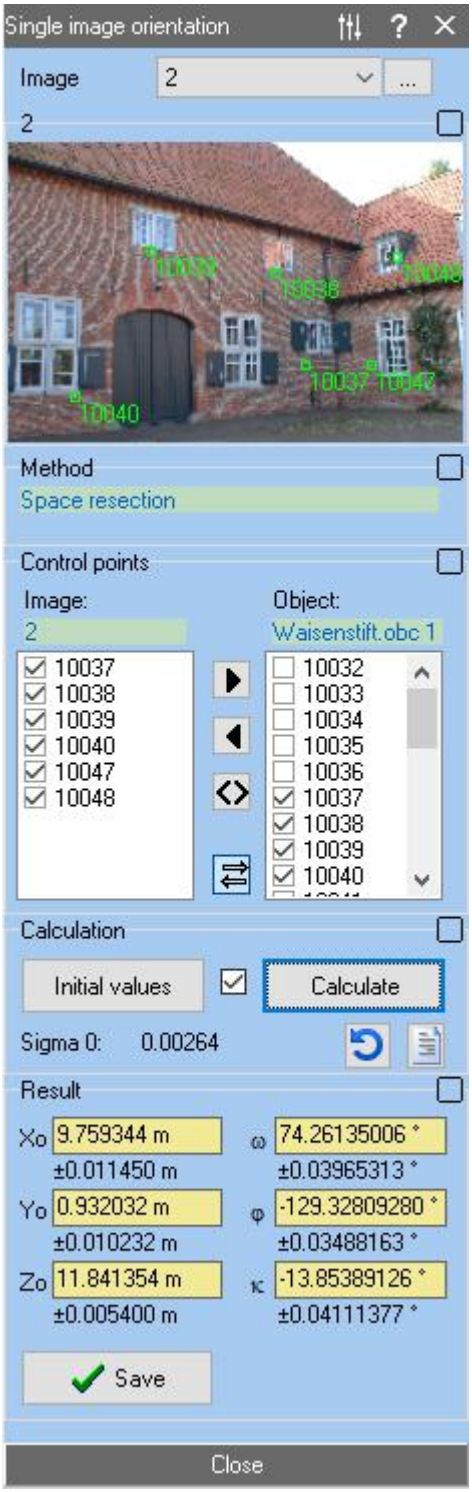


Fig. 73: Docking window for the calculation of space resection

Under certain conditions the parameters of interior orientation can be calibrated by space resection. For the method of *Resection* the corresponding parameters have to be activated under **Edit/Options/Compilation/Orientation**. For this approach of camera calibration a good spatial distribution of control- and image points must be given. The *Direct linear transformation* method always determines five parameters of interior orientation that, however, do not fully fit the implemented standard model of interior orientation and therefore should only be used with caution.

7.2 Relative orientation

Menu:	Orientation → Relative orientation
Precondition:	Existing stereo model

The function **Relative orientation** is used for calculating the relative orientation of a stereo model. The function requires the definition of a stereo model under **Orientation/Stereo models**, where the assignment of the two images to the model, as well as the type of calculation is defined.

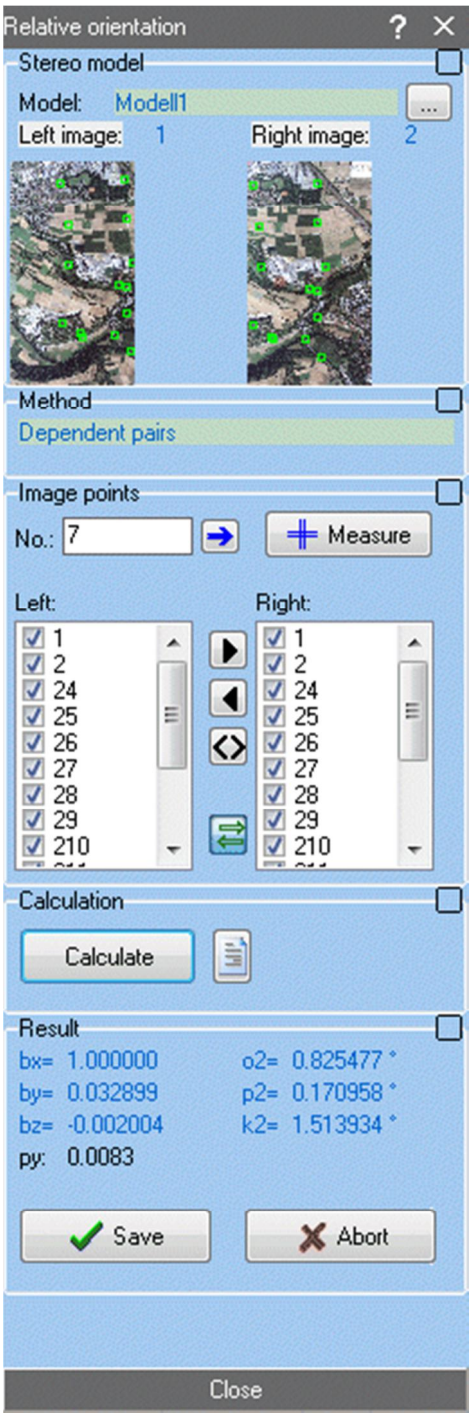


Fig. 74: Docking window for relative orientation

Under Stereo model the desired stereo model is displayed or selected with [...]. The two associated images are shown below and the existing image points are superimposed. By clicking into the overview images the corresponding image windows will be positioned accordingly.

Under Method the calculation method for relative orientation is selected. Available options are:

Dependent pairs The method of dependent pairs calculates the five parameters of the relative orientation so that the image on the left defines the model coordinate system, and the right image is oriented with two translations and three rotations. The base distance between the two images is 1.

Independent pairs The model coordinate system is in the projection center of the left picture with the x axis through the center of projection of the right image. Two rotations of the left and three rotations of the right image are calculated. The base distance between the two images is 1.

Stereo normal case Both images are in parallel, i.e. all rotation angles and the base components by and bz are zero. The base distance is the value that has been set for the base length under the model definition. The measurement of homologous points is not required, i.e. measured image coordinates are ignored.

With the exception of the stereo normal case, the calculation of the relative orientation is done by adjustment based on the coplanarity condition. Settings for adjustment, e.g. an outlier test, are made under **Edit/Options/Compilation/3D calculation** with selection *Relative orientation*.

Under Image points the already measured image points are listed for both images. This points enabled here are used to calculate the relative orientation. With the corresponding popup menu points can be selected, displayed or deleted. The button Measure activates the interactive measurement of homologous points according to the function **Measure/Image coordinates**. The image points are measured alternating in each in the left and in the right image before the next point is measured with the next free point number.

The Calculation of the relative orientation is executed with Calculate. The Result appears where the parameters differ depending on the selected Method for relative orientation. The value of *py* refers to mean y-parallax in the unit of image coordinates. The corresponding calculation log file can see be loaded with button  . With button  the displayed orientation parameters are reset to zero. The displayed values are used as initial values for adjustment.

With Save the result is saved to the currently selected model and the docking window is closed. The model coordinates of the measured homologous points are stored under the current stereo model. They can be displayed and managed under **Orientation/Stereo models**.

7.3 Absolute orientation

Menu:	Orientation → Absolute orientation
Precondition:	Existing stereo model

The function **Absolute orientation** is used for calculating the absolute orientation of a stereo model. This is identical to the function **Objects/3D transformation** (see chapter 9.7), which is used to transform the three-dimensional model coordinates of a stereo model into the three-dimensional control point coordinates of the superior coordinate system. The function requires a current stereo model with valid relative orientation and model points, as well as a selected 3D object, which both must have at least three identical points.

The existing model coordinates of the selected stereo model are displayed in the left list box of the *Source object (xyz)*. There, individual points can be selected.

As transformation function only a 7-parameter similarity transformation is available. After performing the transformation with Calculate the result can be viewed under Output log. The computed transformation parameters are displayed. In box Apply under *Object* the selected points of the source object can be transformed into the object coordinate system using the current transformation parameters. In addition, under *Model* the orientation parameters of relative orientation of the selected stereo model can be transformed into exterior orientations of the two images using the current transformation parameters. Optionally, by confirming with OK the exterior orientations of the two related images in the target coordinate system are also calculated (absolute orientation).

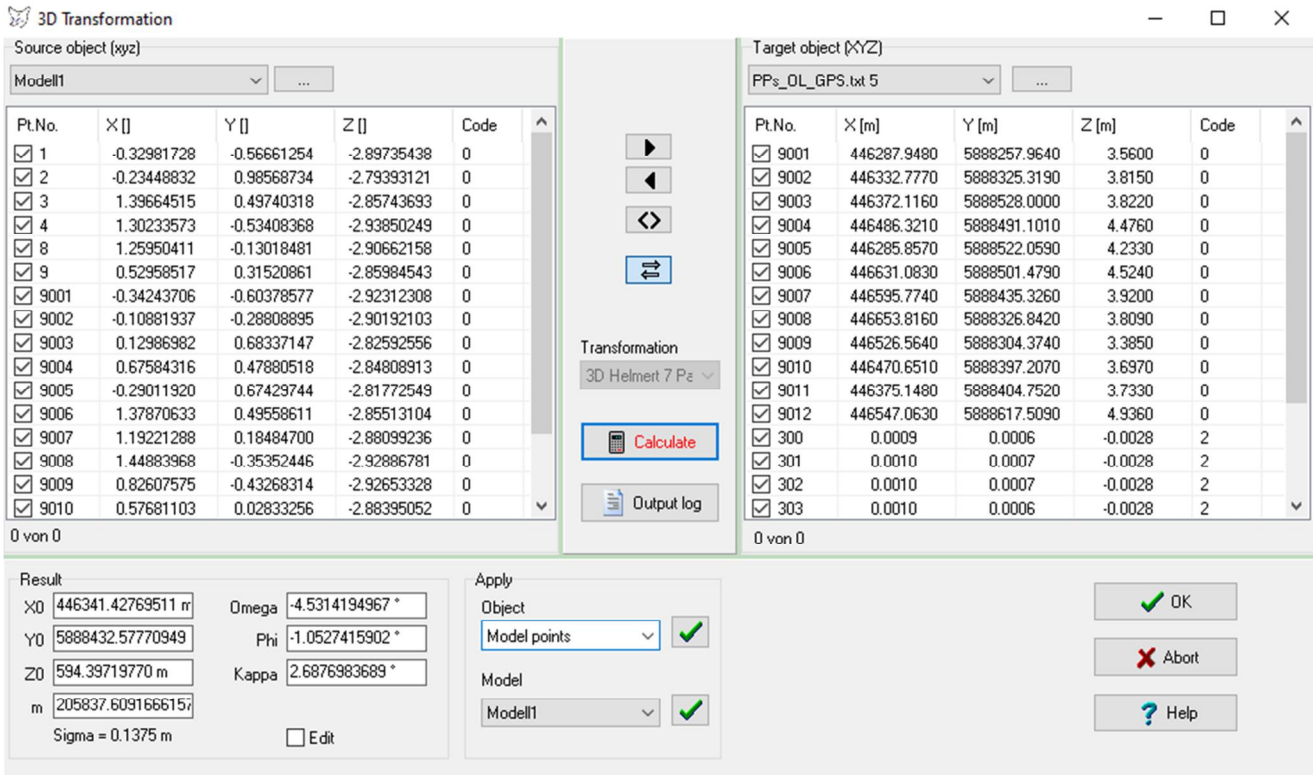


Fig. 75: Window for absolute orientation

7.4 Stereo models

Menu:	Orientation → Stereo models
Precondition:	Min. 2 existing image objects

The function **Stereo models** is used for the generation and management of stereo models.

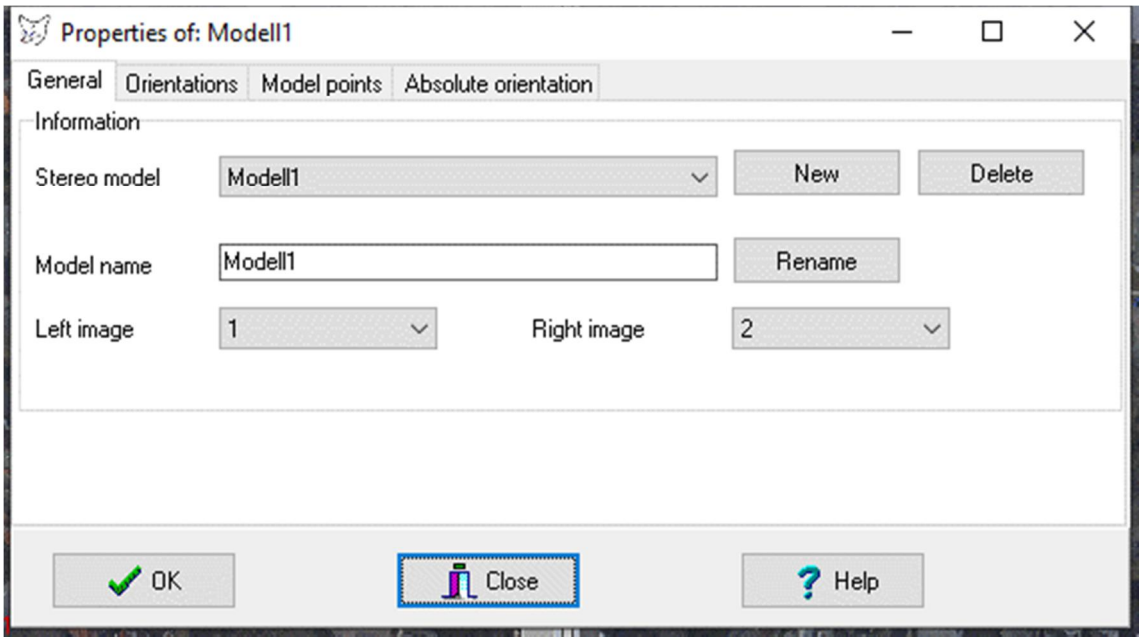


Fig. 76: Definition of a stereo model: general settings

On the page **General** an existing model is selected by the *Stereo model* drop-down list. With New a new model is created. With Delete the current model can be removed from the list and its data is deleted. A new name of the model can be entered under *Model name* and will be accepted with Rename. The two associated images are selected from the list at *Left* and *Right images*.

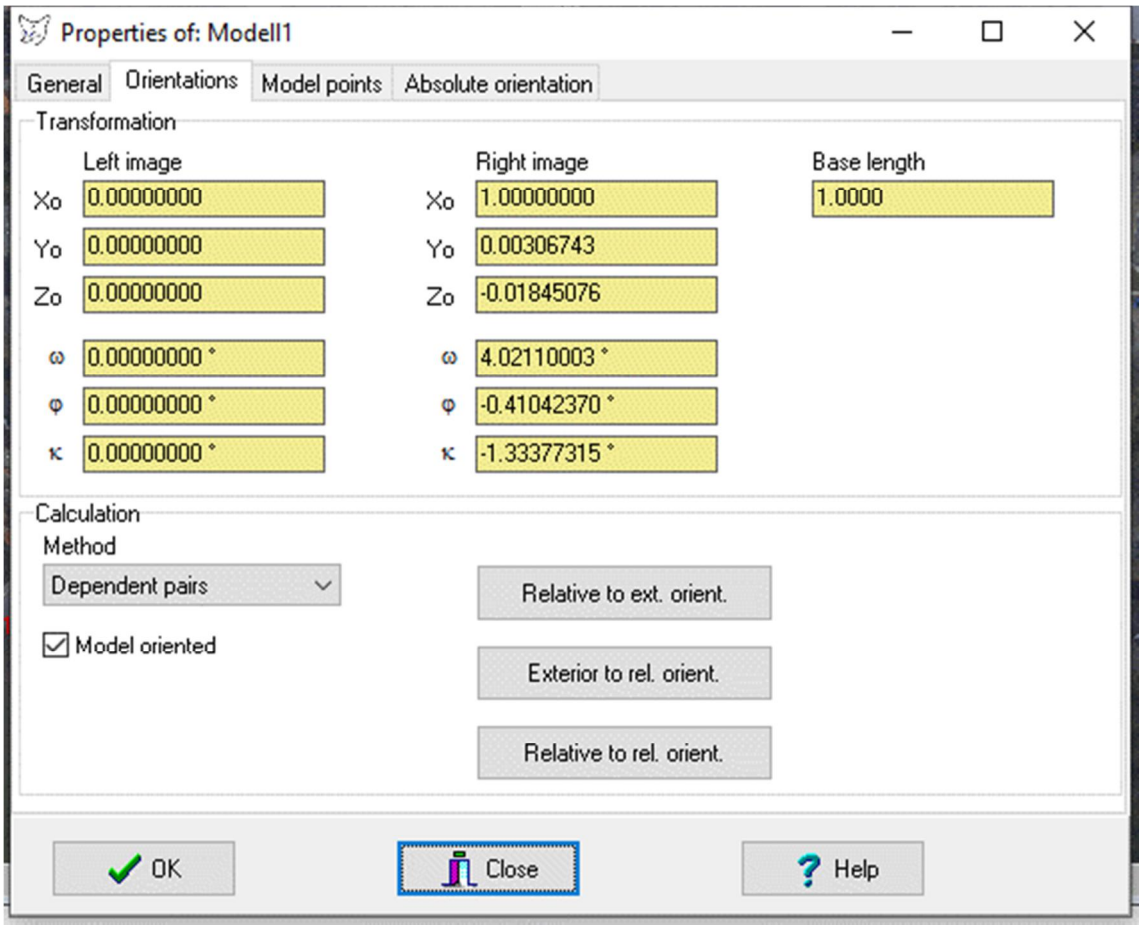


Fig. 77: Definition of a stereo model: orientations

The page **Orientations** displayed the relative orientation data associated with the stereo model for the left and right image each. In addition to the coordinates of the origin in the model coordinate system and the three rotations around the axes of the model system, a *base length* can be entered here which defines the actual metric distance between the two cameras (projection centers). The base length 1 defines a stereo model without absolute scale.

The calculation procedure is selected under *Calculation*. Under *Method* the calculation method for relative orientation is selected. With the button Relative to ext. orient. the shown parameters of relative orientation are converted into exterior orientation of the two images. Here the entered *base length* is used as scale factor for the translations of exterior orientation. Existing parameters of exterior orientation will be overwritten. With Exterior in rel. orient. existing data of exterior orientation of the two images are converted into relative orientation according to the chosen calculation method. With Relative to rel. orient. existing data of the relative orientation is converted into a relative orientation according to the method of calculation chosen, e.g. from the model of independent image pairs to the model of dependent image pairs. The checkbox *Model oriented* indicates if a relative orientation is existing for the model.

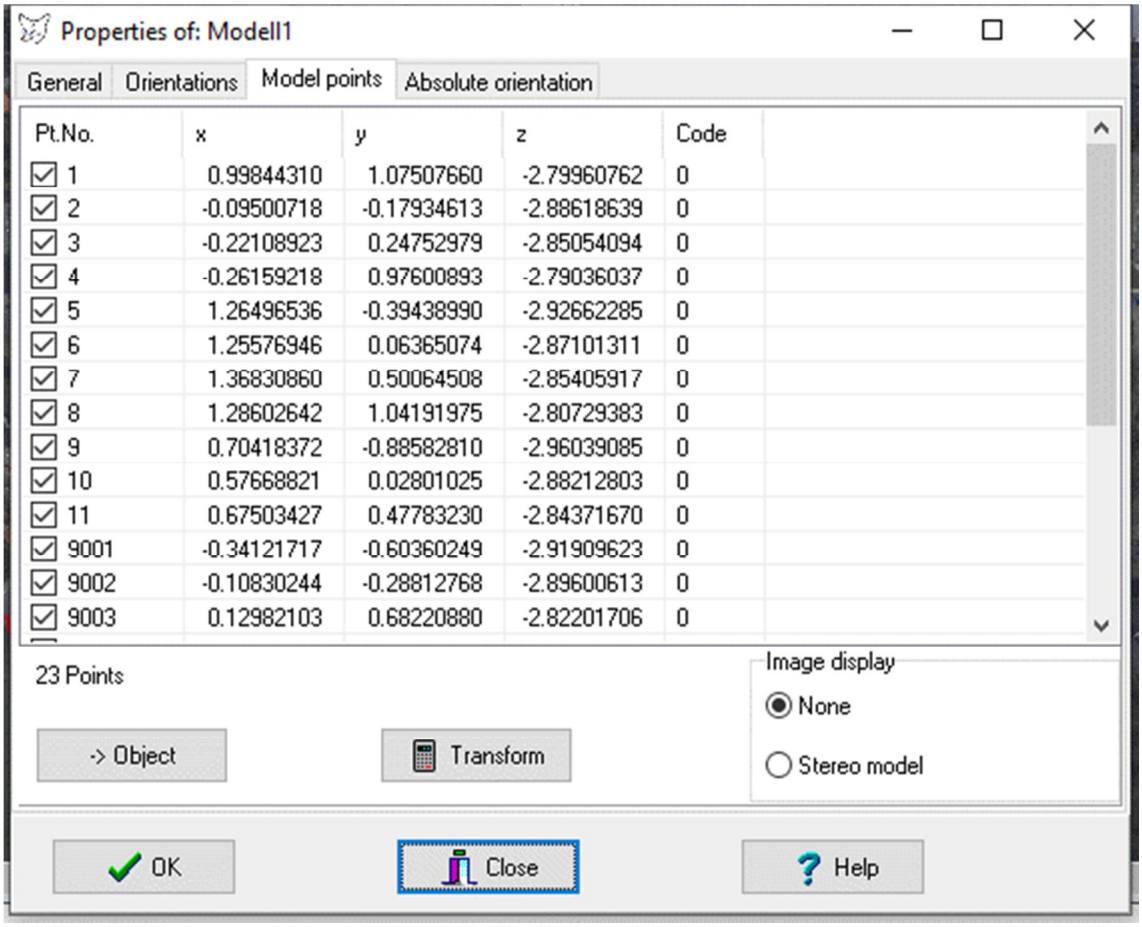


Fig. 78: Definition of a stereo model: model points

On page **Model points** stored model coordinates of the stereo model are displayed and managed. The individual items can be edited using the associated popup menu.

With the button -> Object the model coordinates are copied into a 3D object with the name of the stereo model and can then be processed like any other 3D object. The button Transform is used for the transformation of the selected points, e.g. scaling, translation or rotation. Under *Image display*, it is controlled whether the selected point should appear in the corresponding image windows of the stereo model.

On page **Absolute orientation** the transformation parameters of absolute orientation associated with the current stereo model are displayed. Reference object denotes the object that contains the ground control points used for absolute orientation. The data cannot be edited.

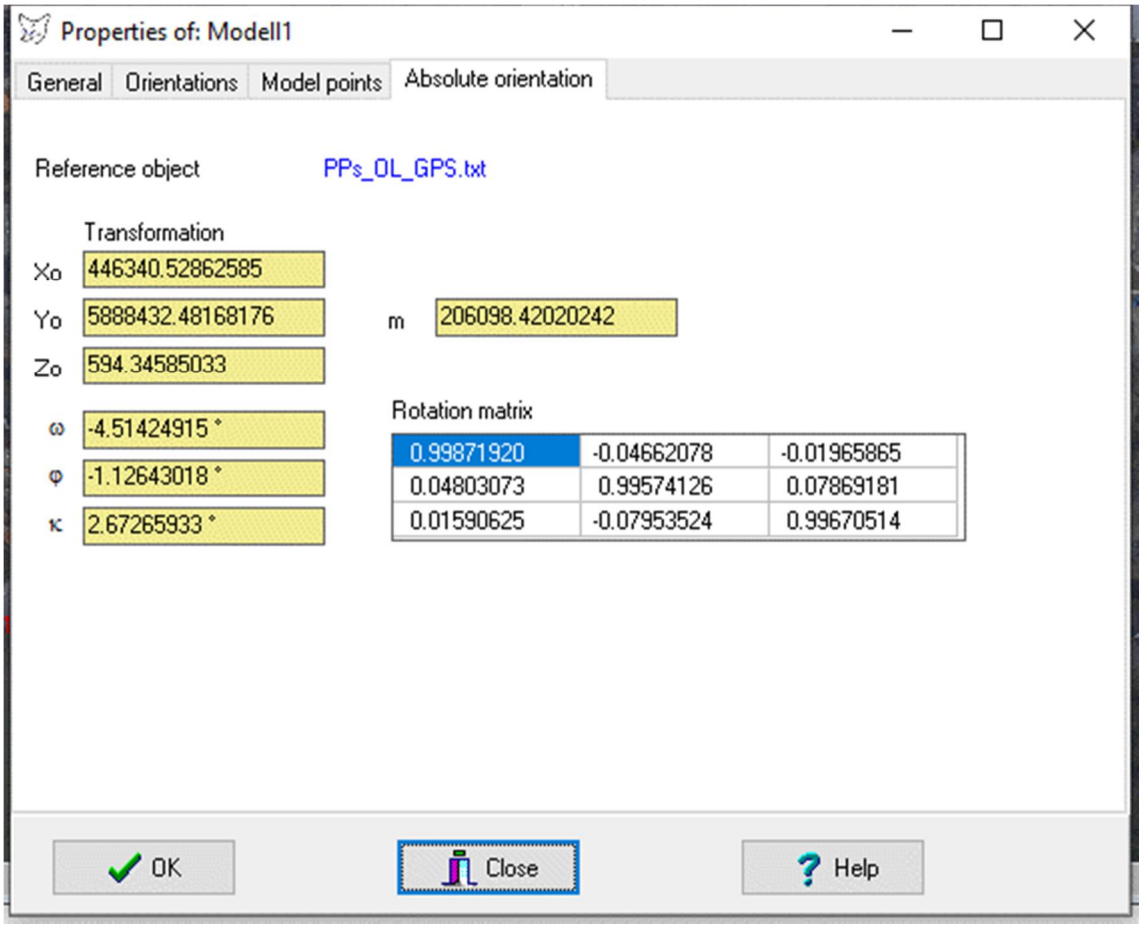


Fig. 79: Definition of a stereo model: model points

7.5 Rotation matrices

Menu:	Orientation → Rotation matrices

The function **Rotation matrices** is used for the analysis of rotation matrices and rotation angles of the image to demonstrate their effect and meaning. Changes of parameters do not affect the parameters of the image.

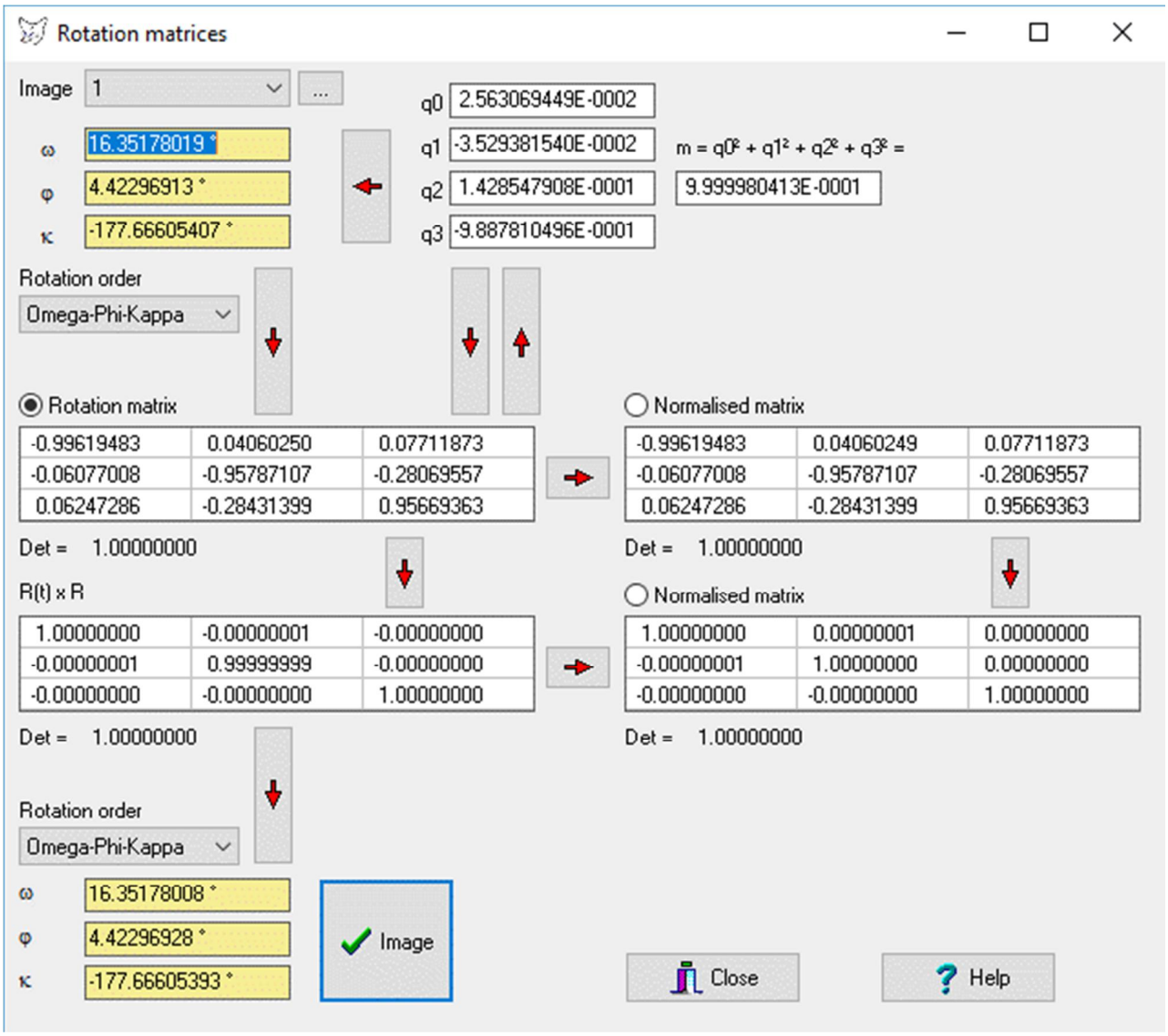


Fig. 80: Rotation matrices

An existing image can be selected under *Image*, its rotation parameter of exterior orientation under the rotation angles ω, φ, κ or, if available, with their quaternions *a*, *b*, *c*, *d,* are displayed in the field *Rotation matrix*. The button with calculates each new rotation matrices or rotation angles from the input values above. The values of the rotation matrices can be edited freely.

From the rotation matrix the unit quaternion (*q0*, *q1*, *q2*, *q3*) can be calculated with , and from the Euler angles ω, φ, κ and the rotation matrix can be derived. The parameter *m* represents the norm of the quaternion (default = 1).

From the above rotation angles ω, φ, κ and the selected *Rotation order* the *Rotation matrix* is calculated and displayed. The button calculates the *Normalized matrix*, i.e. a possible deviation from orthogonality and orthonormality of the rotation matrix is fixed according to the Gram-Schmidt process and the result is displayed.

The button  calculates the results from the above matrices. The matrix *R(t) x R* must give an identity matrix if the rotation matrix is orthonormal. This matrix can be normalized again, if the right switch  is pressed.

Finally, the rotation angles from the each activated rotation matrix can be extracted again taking into account the below defined *Rotation order*. These rotation angles may be ambiguous due to the applied trigonometric functions.

8 Menu Rectification

The menu **Rectification** provides functions for the rectification of images.

8.1 Image rectification

Menu:	Rectification → Image rectification
Precondition:	Existing image object with bitmap and activated object

The function **Image rectification** is used for the calculation of single image rectifications or image mosaics. For this purpose different mathematical approaches are available. Prerequisite for the start of the function is an active image with a loaded bitmap and an existing object. If a camera is associated with the image or distortion parameters are present, the image coordinates are corrected for distortion before the image is rectified.

Currently, two approaches are implemented that can be selected below the image list:

Single image: Here, only the currently selected image is rectified and the calculated transformation coefficients are assigned to the image. This mode is to select, if no transformation in object space is saved to the current image, or if only a single image should be rectified.

Image mosaic: An arbitrary number of images can be combined to an image mosaic. It requires the previous calculation of a transformation into the object space, i.e. either a plane coordinate transformation or an exterior orientation, which must be associated with each image involved.

The process of rectification is basically as follows:

1. Select of one or more images
2. Selecting the calculation method under Options
3. Depending on the method, selection of image and object points under Control points
4. Start calculating transformation with Calculate for projective rectification
5. Definition of the dimensions of the output area under Dimensions
6. Preview of the result image with Preview
7. Generate a new image object with the rectified image by Create

In the image list the images to be rectified are marked by the checkbox. By simply clicking on an image name, a reduced image of the original is displayed below the list. In addition the name of the currently selected image and the related object transformation appear in the bottom status bar. When an image is selected, the corresponding list of existing image coordinates is updated under Control points.

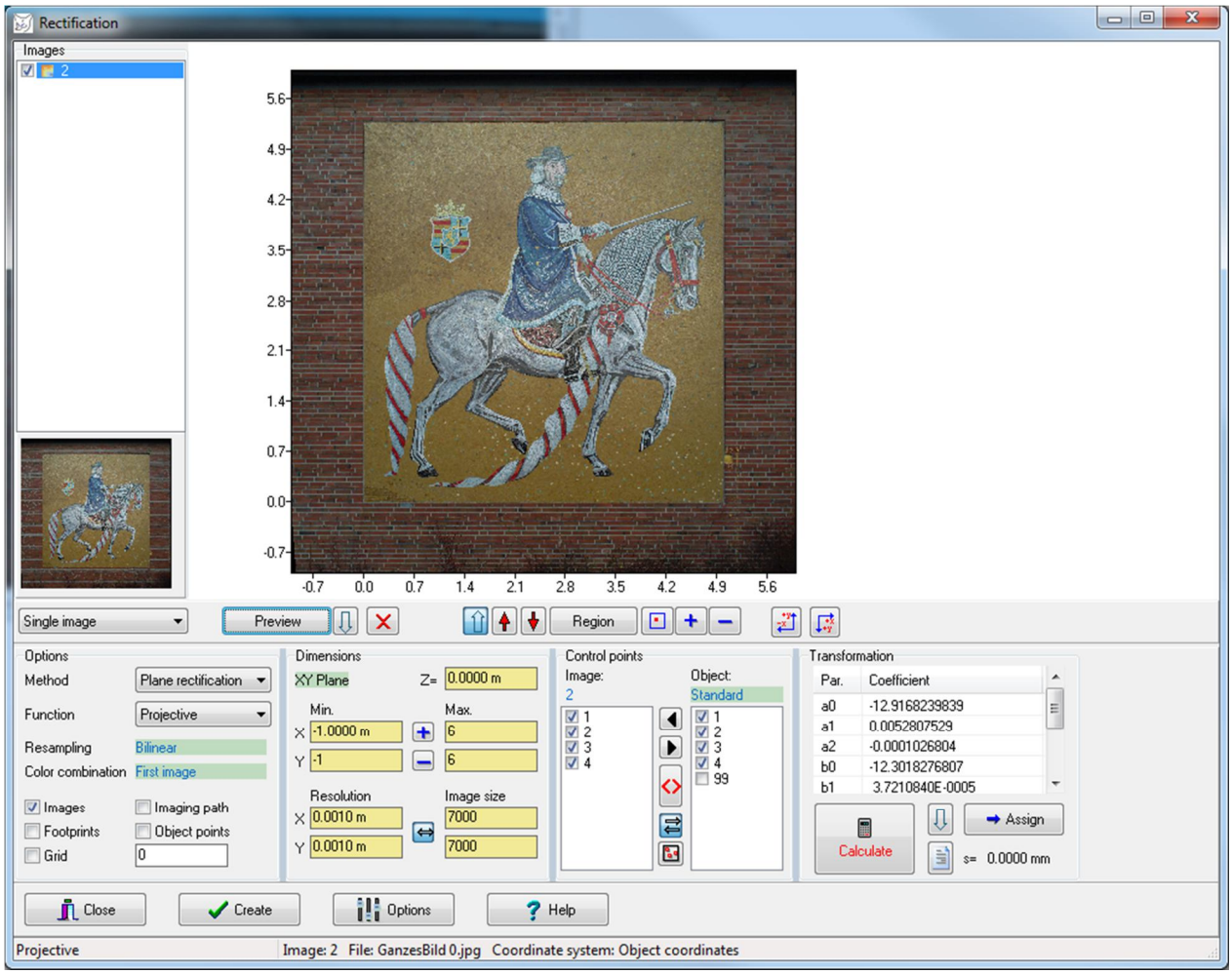


Fig. 81: Window for image rectification

With the button Preview a reduced result image is displayed if correct inputs have been made according to the chosen method of calculation. The preview image corresponds to the subsequently rectified image. With button the drawing area is equivalent to the maximum dimensions from the selected object. With the area is calculated from the position parameters of exterior orientation from the selected images. With button the rectified object area and the drawing region will be adjusted so that the complete rectified image or mosaic will be displayed. The represented drawing area can be adjusted with button Region. Alternatively, the rectification area can be defined by mouse movement. With an area around a center point can be defined. The buttons and enlarge or reduce the drawing area. With the dimensions under Dimensions are used as drawing area. With the current size of the drawing area is transferred to Dimensions. The final rectified image has always the size specified in Dimensions. The button turns the auto preview on or off. The switch clears the preview. The buttons and flip the rectified image along the X-axis and/or the Y-axis.

Under Options calculation and display parameters are shown. They can also be adapted through the button Options. Under *Method* the following procedures for image rectification are available:

Plane rectification: The entire image is rectified with one single plane coordinate transformation that is chosen under *Function*. The transformation coefficients are calculated with the image and object coordinates defined under Control points.

Exterior orientation: The rectification is carried out with the data of interior and exterior orientation of the image. It transforms all points of the selected reference plane in the selected distance *Z* with the help of the collinearity equations back into the image.

Differential correction: The image is differentially rectified onto a digital surface model (orthophoto). This must be a surface model in the form of a terrain model (DTM) or a TIN (triangular meshing).

The mathematical function to the selected *Method* is set under *Function*. The selection offers only such functions that match with the selected method. For the method *Plane rectification* the following options are available:

Projective The rectification is carried out using the plane projective transformation (8 parameters). A minimum four identical image and control points is required. The transformation strictly describes the central projective imaging of a plane in object space.

Affine The rectification is carried out using the plane affine transformation (6 parameters). A minimum three identical image and control points is required. The affine transformation does not take any perspective distortion into account, thus it is e.g. suited for the rectification of scanned maps.

Polynomial The rectification uses a polynomial transformation of degree n. The number of the transformation parameter is u=(n+1)(n+2), the minimum number of identical image and control points is u/2. The polynomial transformation is suitable for the rectification of nonlinear deformed images, such as satellite images of the earth or images of curved surfaces.

Helmert The rectification is carried out using the plane Helmert transformation (4 parameters). A minimum two identical image and control points is required. The Helmert transformation does not take into account any perspective distortion and is e.g. suited for the rectification of scanned maps, if no shear and scale differences exist in the coordinate axes. The function will produce meaningful results only for metric image coordinates, left handed-oriented pixel coordinates are incorrectly processed.

Bilinear Not implemented.

For the method of *Differential rectification* the following functions can be selected:

Orthophoto DTM The selected object must have to a point cloud, which is organized in a regular grid (digital terrain model DTM). The orthophoto calculation is conducted in the classical way, in which all points of a reference plane (XY) are interpolated in the DTM and thus obtain a Z value. Then, the corresponding image point is calculated using the collinearity equations.

Orthophoto TIN The selected object must have a TIN (triangular meshing). The orthophoto calculation is performed so that each orthophoto image point is converted into a ray in object

space, whose intersection with the TIN is determined. This 3D point then is back-projected into the associated images from which the corresponding color value is taken. The procedure may require longer computation times, especially for a high number (e.g. >200000) of triangles.

By clicking on the *Color interpolation* method the type of resampling is set. Available options are:

Nearest neighbour	The grey or color values are calculated by rounding of the fractional position of pixels in the original image.
Bilinear	The grey or color values are calculated by bilinear interpolation of the fractional position of pixels in the original image.
Bicubic	The grey or color values are calculated by bi-cubic interpolation (bicubic convolution).

The method of *Color combination* defines how the color or grey values in overlapping areas of adjacent images are calculated. Default setting is *First image*, i.e. the color value is taken from the first image in the image list. Further explanations can be found under **Edit/Options/Compilation/Rectification**.

The appearance of the preview is controlled by more options.

Images	The resulting image plan is drawn into the preview
Imaging path	Draws a line of consecutive image paths, for example, the path of an aerial flight
Footprints	Represents the object area covered by the image (footprints)
Object points	Displays the object points (green: selected points; red: all other points); optionally residuals of the object points can be plotted (see **Edit/Options/General/Display**)
Grid	Represents a grid in the defined grid width

Under Dimensions the object area is set to where the desired image is rectified. The rectangular area of the object is defined by input of corner coordinates, X and Y (min/max). The size of a corresponding pixel in the object space (also GSD = ground sample distance) is entered under *Resolution*. This results in a corresponding image size of the result image. If the button ⇔ is pressed, changes of *Resolution* or *Image width* are adapted automatically to each other. Clicking on the *XY-plane* field, the reference coordinate plane can be selected in which the image is to be transformed. Here, the main coordinate planes *XY*, *XZ* and *YZ* can be selected as well as a *best-fit plane* that is arbitrarily oriented in space. The best-fit plane can be calculated under **Objects/Calculations** and must be defined by appropriate plane parameters in the selected object. The displayed *Z* value indicates the distance from the reference plane.

Under Control points identical points for the selected image and object are listed. Image points and ground control point coordinates can be directly measured in **Measure/Ground control points**. They can be selected through the corresponding popup menu. All marked points are used for calculating the coordinate transformation. If more points than minimally necessary are selected, the transformation parameters are calculated by least-squares adjustment. With the button  the minimum and maximum coordinate values of the selected object points are transferred to the field Dimensions.

The field Object will be shown for the methods *Exterior orientation* and *Differential rectification*. Here the desired reference object can be selected and the corresponding object points, points of a point cloud and triangles can be displayed. With the button  the minimum and maximum coordinate values of the selected object are transferred into the field Dimensions.

Under Transformation the computed transformation parameters are displayed if the method *Plane rectification* has been selected. The coefficients a0 to c2 refer to the plane projective transformation which also can represent transformations such as affine and Helmert transformation. With Calculate the transformation is calculated using the selected points. The calculated coefficients and the standard deviation s0 are displayed. The button  turns the automatic calculation on or off. With the button Assign the displayed (and maybe manually modified) coefficients are assigned to the current image (with Yes) or all images (with All). With  the related calculation logfile can be displayed.

With Create the final image in the predicted size is generated after confirmation and saved as a new image object. In the rectified image, image and object coordinates of the mouse position can be displayed, if the mouse coordinate window (**Windows/Mouse coordinates**) is visible. The image coordinates of the corresponding image are given in the object coordinate system, i.e. a measurement of image coordinates in **Measure/Image coordinates** leads directly to object coordinates. Alternatively, with the function **Measure/Object coordinates** object coordinates can be measured within the rectified image, if the 3D method *Projective transformation* is set to the image.

8.2 Image to image

Menu:	Rectification → Image to image
Precondition:	Opened image window

The function **Image to image** is used for the rectification of one image to a different image with the help of a plane coordinate transformation. Prerequisite for the start of the function is an active image with a loaded bitmap. A sufficient number of identical points must be measured in the source image (image 1) and in the target image (image 2). If a camera is associated with the images or distortion parameters are present, the image coordinates will be corrected for distortion.

Under Preview a reduced preview image of the rectification result will appear. Under Method the projection model and related parameters are defined according to **Rectification/Plane rectification**. The option *Distortion-free* generates a distortion-free result image.

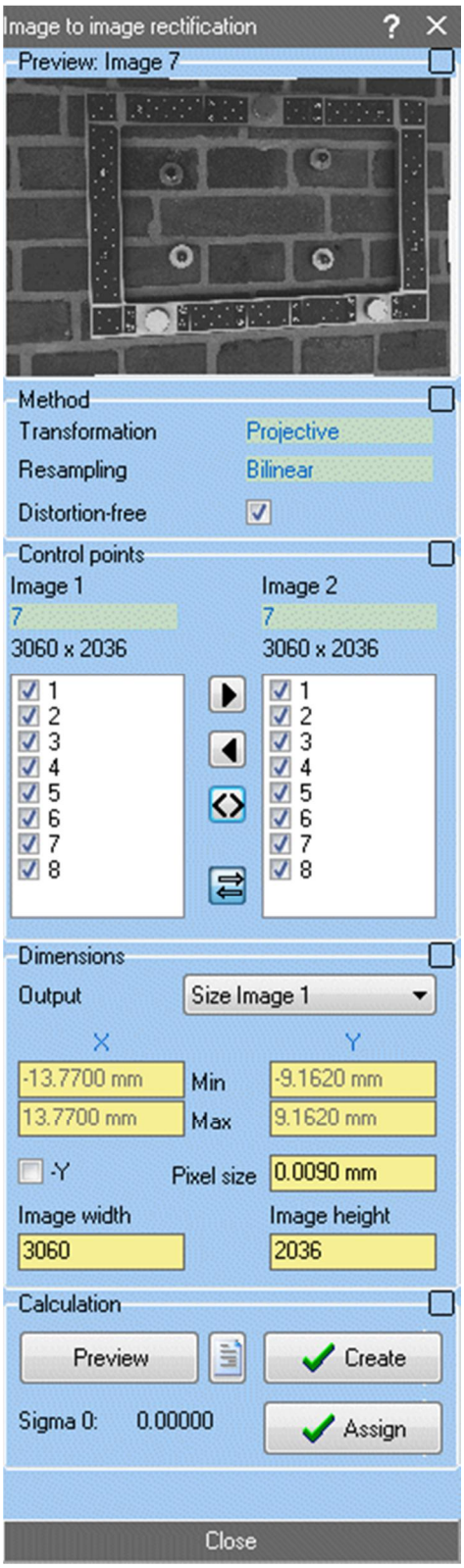


Fig. 82: Docking window for image to image rectification

Under Control points the two images are selected (click on green box) and the existing identical points are listed. Points can be enabled or disabled for calculating the coordinate transformation. If more points than minimally necessary are selected, the transformation parameters are calculated by least-squares adjustment.

Under Dimensions the image area of the result image is set to which the source image is rectified with a desired *pixel size*. All entries are defined in the unit of image coordinates. Under *Output* it can be selected, which portion

of the image is used to define the dimensions. Option *Size Image 1* creates an image in the size of the source image, *Size Image 2* produces an image in the size of the target image. *Controls points* sets a minimum area to the selected identical points and *Individually* allows to define an arbitrary size. The rectangular area of the result image is defined by input of corner coordinates, X and Y (min/max). The size of the corresponding pixel size is entered under *Pixel size*. This results in a corresponding image size of the result image that can be displayed or entered under *Image width* and *Image height*. The option *-Y* generates an image that is mirrored at the X-axis.

The button Preview generates an updated preview image that is also automatically updated when changes to the settings have been made. With Create the final image in the predicted size is generated after confirmation and saved as a new image object. The rectified image receives the interior and exterior orientations of Image 1. With Assign only the computed transformation parameters are assigned to the input image, a new image is not created.

8.3 Image transformation

Menu:	Rectification → Image transformation
Precondition:	Opened image window

The function **Image transformation** is used for generating geometrically transformed or distortion -free images.

Under Preview a reduced preview image of the rectification result will appear.

Under Method the *Resampling* function and the coordinate *Transformation* can be selected. Clicking on the resampling method opens the settings in **Options/Rectification**. Clicking the selected transformation toggles between the implemented functions such as (projektive, affine, polynomial etc.) and controls the related input of coefficients.

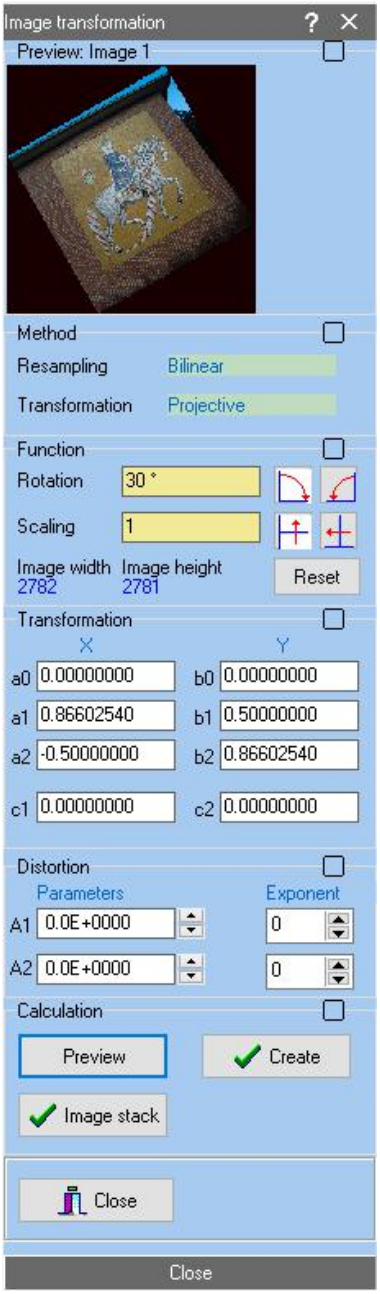


Fig. 83: Docking window for image transformation

Under Function rotation angle and scaling factor can be set. The resulting new image size will be shown under *Image width* and *Image height*. The displayed buttons calculate the transformation parameters for image rotations +90° and -90°, and reflections at the X- or Y-axis. The button Reset resets all input values to their default settings.

Under Transformation the transformation coefficients of the selected coordinate transformation are displayed. Arbitrary values can be set as long as the resulting image size in the range [1... 20000] is not exceeded.

Under Distortion the distortion parameters A1 and A2 of the current image are displayed. They can be changed interactively with the spin buttons or by entering a new value. The spin buttons change the value as a function of the defined exponent. Accurate distortion-free images can be calculated, if calibrated distortion parameters are

saved to the current image and the transformation coefficients are reset with Reset. Then the image geometry is not transformed, hence only the distortion correction is applied.

The button Preview generates an updated preview image that is also automatically updated when changes to the settings have been made. With Create the result image is generated after confirmation in the predicted size image and saved as a new image object.

With the button Image stack a list of images can be processed with the current transformation. If necessary, the bitmaps of the selected images are loaded temporarily. Result images are stored in the image list under the name "transformation of image X".

8.4 Normal case images

Menu:	Rectification → Normal case images
Precondition:	2 existing image objects with bitmaps or stereo model with bitmaps

The function **Normal case images** is used for generating normalized stereo images (epipolar images). Both images of a stereo pair are rectified such that distortion-free images are created with an equal principal distance according to the normal case of stereo photogrammetry.

Under *Left image* and *Right image* the two desired images are selected to which a bitmap must be loaded each. In this case the normalized images are created in the coordinate system in which the exterior orientations of the images are defined (mode: *absolute*). Alternatively, if an existing stereo model is chosen under *Stereo model*, the normal images are created with respect to the model coordinate system (mode: *relative*). The relatively-oriented model should be calculated according to the procedure of the independent pairs of images, because otherwise it may cause significant distortions in the resulting right image. After selecting the images, the two related images are displayed.

Under *Principal distance* the final principal distance (camera constant) is entered that will be assigned to the normalized images. The principal distance of the left image appears as the default value.

Under *Image format*, the size of the normalized images is set.

Input image	The normalized images get exactly the size of the input images
Optimal size	The size of the normalized image is calculated to fit the image content in the image. This left and right may result differently sized images.
User defined	The specified sizes are used for the size of the normalized images.
Window	A rectangle appears in the images that can be changed with the mouse. If both rectangles are marked (Shift + mouse click), moving or resizing is performed

simultaneously in both images. The button sets the area to the maximum displayable size.

The resulting number of pixels is automatically displayed under the input fields. The pixel size of the normalized images is identical to the input image resolution. If the button is enabled, both images have always the same size. The buttons and flip the rectified image along the X-axis or the Y-axis.

The button Preview generates a preview of two normalized pictures. In the preview window, a horizontal bar can be moved with the mouse to check for any y parallaxes between the images. For this function the option *Epipolar lines* under **Edit/Options/General/Graphics** must been activated.

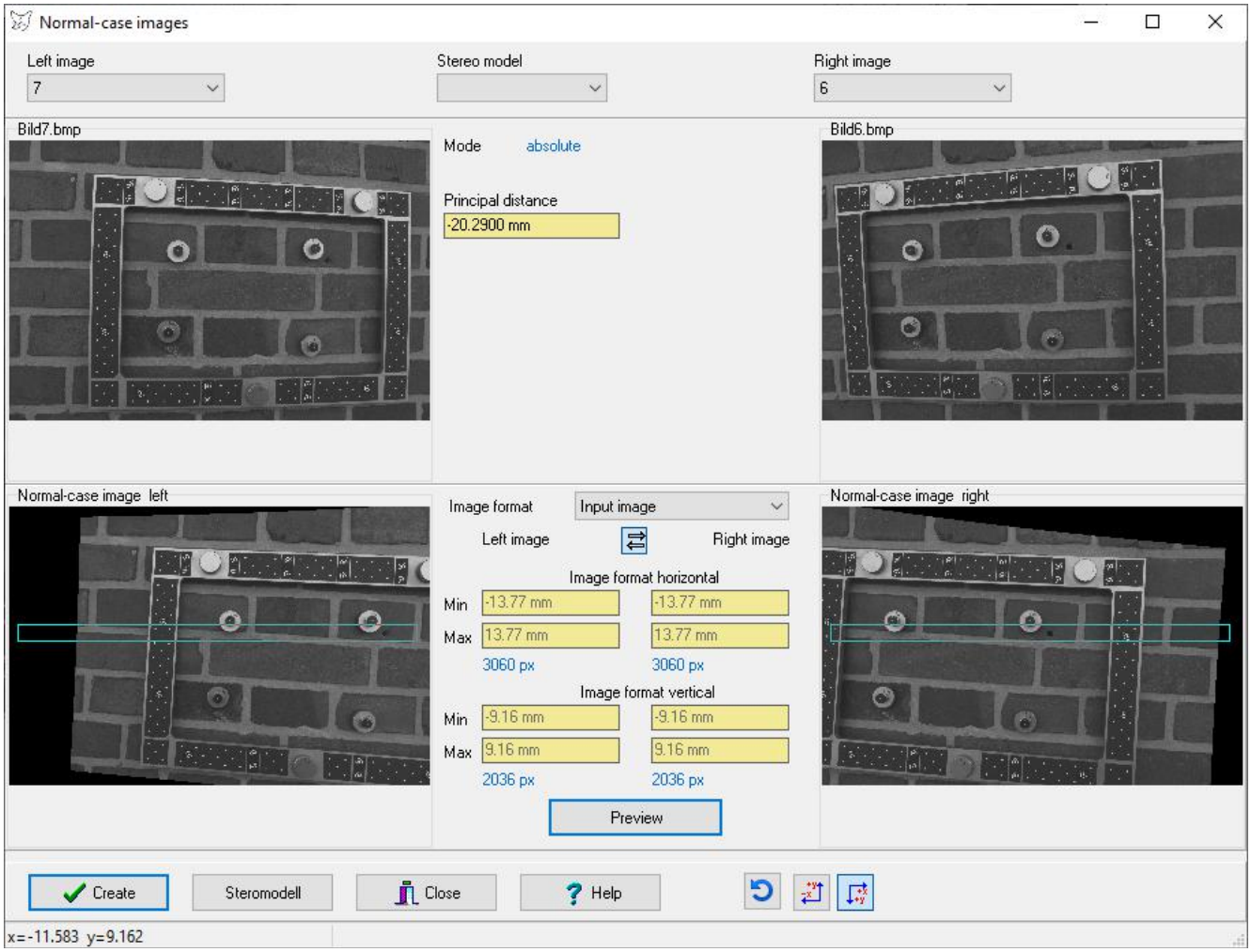


Fig. 84: Creation of normalized stereo images

With Create the calculated normalized images are generated and saved as new image objects. For large output images (more than 300 MB) the image size is reduced by a factor of two and the related physical pixel size is doubled. The interior orientation of normalized images is distortion-free. Depending on the image size, the principal point may lie outside of the image. The exterior orientation of the images is calculated such that the position of normalized images (X_0, Y_0, Z_0) is identical to the input images and the rotation angles are equal for both images, i.e. they are parallel to each other.

With Stereo model both normalized images are generated and a new stereo model with both images is created.

8.5 Anaglyphs

Menu:	Rectification → Anaglyphs
Precondition:	2 existing image objects with bitmaps or stereo model with bitmaps

The function **Anaglyphs** is used for generating anaglyph stereo images (red/green images). The two input images are superimposed, whereby the left image is colored in red and the right image is colored in green or cyan, according to the select color mode. Preferably, both input images are rectified as epipolar images (normal case images).

Under *Left image* and *Right image* the two desired images are selected to which a bitmap must be loaded each. After selecting the images, the two related images appear under *Input image*.

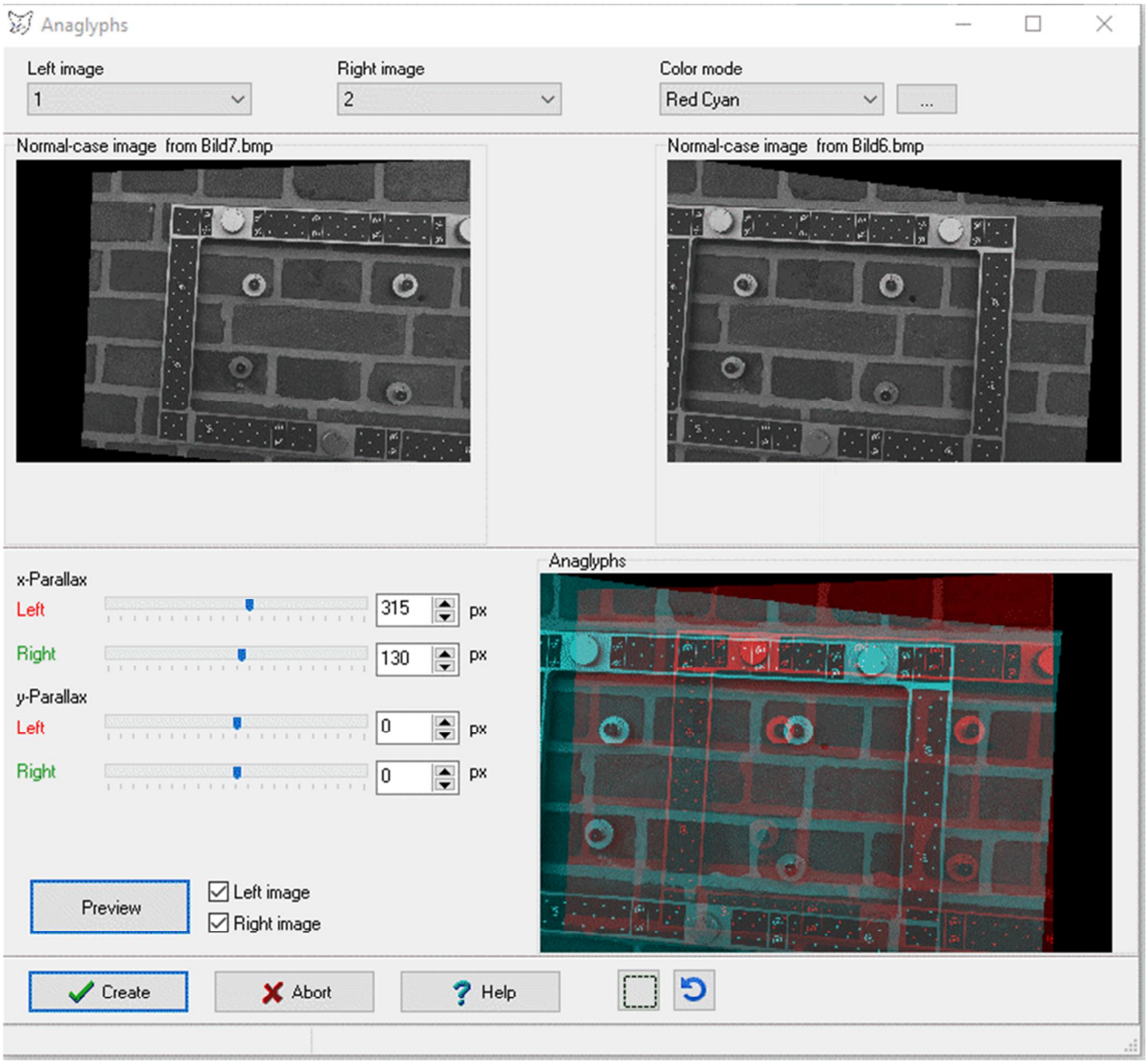


Fig. 85: Creation of anaglyph images

The images are superimposed according to the selected color mode. The following modes are implemented:

Red Cyan	The left image is coloured in red, the right image is coloured in cyan.
Rot Green	The left image is coloured in red, the right image is coloured in green.
Red Blue	The left image is coloured in red, the right image is coloured in blue.
Color	The left image is coloured in red, the right image is coloured in cyan. Here only the red information of the left image and the blue and green information of the right image is used.
Half color	The left image is coloured in red, the right image is coloured in cyan. Here only the grey intensity information of the left image and the blue and green information of the right image is used.
Optimized	The left image is coloured in red, the right image is coloured in cyan. Here only the blue and green information of the left image and the blue and green information of the right image is used.
Dubois	The left image is coloured in red, the right image is coloured in cyan using different weighting factors.

Custom User-defined factors are used for colour adjustment.

The parameters of colour mixing can be edited with button [...]. The following window is displayed:

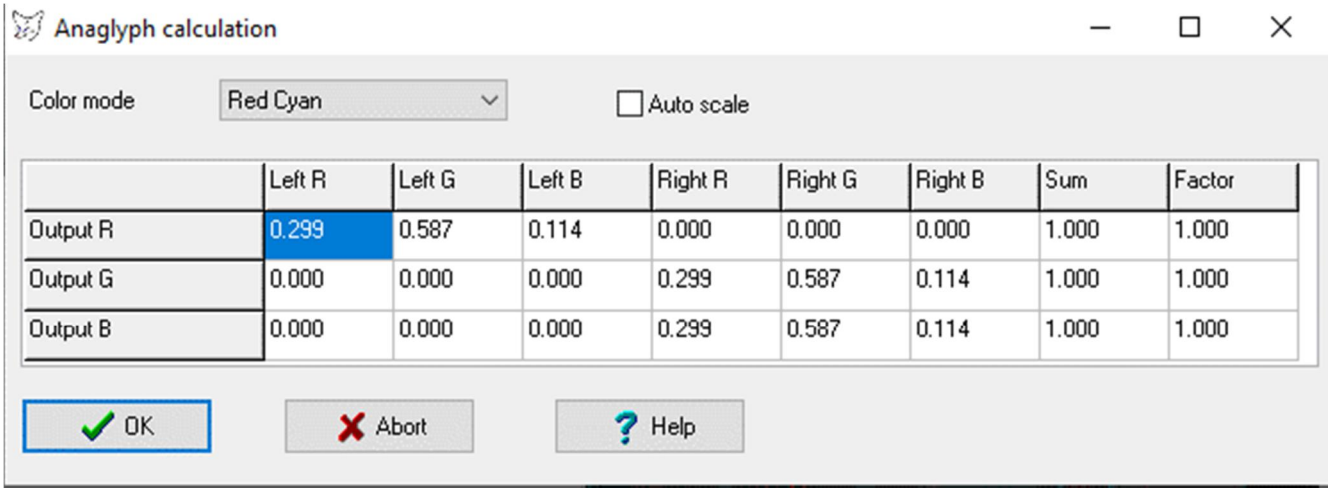


Abb. 86: Calculation of anaglyph colours

The table describes which colour components of the input images are assigned to the RGB components of the output image (anaglyph image). The individual colour components are multiplied by the value in the table and added to the output value. In the *Custom* colour mode, own factors of the colour components can be entered. If *Auto scale* is activated, the sum of the factors is scaled to 1. Thus, the brightness of the original images is maintained. Higher factor sums lead, for example, to a brightening of the result image.

Under *x-Parallax*, a relative displacement in the horizontal direction can be set for the left and right input image. Under y-Parallax, a relative displacement in vertical direction can be set for the left and right input image. The preview picture shows the resulting effect.

With the button a rectangle is displayed in the preview window that defines the image section to be created later. After clicking on the rectangle, position and size of the area can be changed with the mouse. The button sets the area to the maximum size.

The button Preview generates a preview of the anaglyph. Any y-parallax interfering with the subsequent visual 3D impression can be corrected using the appropriate sliders. The desired depth is controlled by the sliders for x-parallax. The options *Left image* and *Right image* control the display of each input image.

With Create the anaglyph in the visible area is generated and saved as a new image object. The anaglyph has no defined parameters of interior and exterior orientation.

8.6 Distortion-free

Menu:	Rectification→ Distortion-free
Precondition:	Existing image object with bitmap

The function **Distortion-free** is used for generating distortion-free images.

Under Images the desired images are selected to which a bitmap must be loaded. The corresponding checkbox must be set for selection. The distortion-free image is calculated so that the principal distance corresponds to the input image, all other parameters of interior orientation will be zero, also the principal point.

Under Mode the method for the determination of distortion parameters is set:

Original Uses the calibrated parameters of the image (default).

Manually Uses the parameters A1 and A2 as they are defined in the input fields Manually. All other distortion parameters (e.g. B, C) are set to zero.

Straight lines The distortion parameters are determined by measurement of points on straight object lines, which are represented as curves in the image (not yet implemented).

Under Manually the distortion parameters A1 and A2 can be defined interactively via sliders or entering new values into the input fields. The fields marked with E set the exponent of the distortion parameters. The button 0 resets the parameters to zero.

Under Options the following parameters can be set:

Original size Creates an image in the same size as the input image.

Minimum size Creates an image that contains only image information, i.e. no background pixels of nonprintable areas of the original image.

Maximum size Creates an image in which the entire image information of the input image is available. This setting can cause very large output images at large distortion effects.

Manually Creates an image in a format that has been defined using the input fields. The format limits are adjusted automatically so that the resulting image format is an integer multiple of the pixel size.

The option *Grid* displays a grid in the image, representing the effect of the distortion.

The option *Center image* creates an output image where the principal point is located in the center of the bitmap. This option is only meaningful for the settings *Minimum size* and *Maximum size*.

With *Inverse*, a distorted image instead of a distortion-free image will be created. For this purpose, distortion data must be assigned to (actually distortion-free) input image.

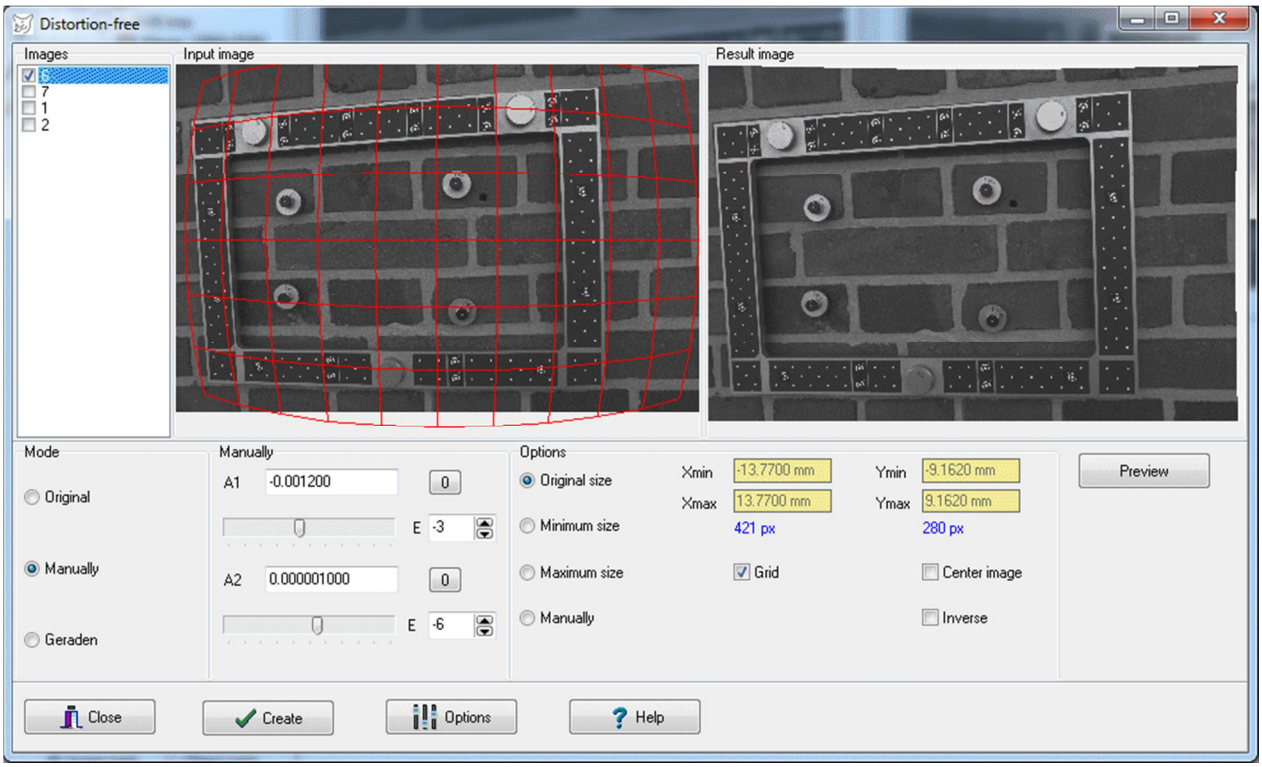


Fig. 87: Creating distortion-free images

With Preview a scaled-down thumbnail can be displayed. With Create all selected images are rectified and stored as new image objects.

9 Menu Objects

The menu **Objects** provides functions for the measurement, processing and visualization of 3D objects.

9.1 Object properties

Menu:	Objects → Object properties
Precondition:	Loaded project

The function **Object properties** is used for the management of 3D objects. Under Selection the desired object can be selected. A new object can be generated with New. With Delete the selected object is removed from the list and its data is deleted. A new name of the object can be entered under *Object name* and will be accepted after pressing Rename.

With the option *Visible* the current object can be enabled or disabled. Disabled objects are excluded from graphical display of object points, polygons, or deformations. Under **Edit/Options/Visualization/Objects** all existing objects can be enabled or disabled. The function can also be performed via the context menu of the project tree. The color of the object can be set using the color box.

Optionally, each object can contain any number of object points (object coordinates). Individual points can be topologically connected to polygons, where each object can have as many polygons. Furthermore, point clouds can be loaded to the object, which are used for the representation of object surfaces (for example in the calculation of orthophotos).

9.1.1 Object

The page **Object** displays general information about the object.

Under Information the number of items saved to the object (object points, polygons, point cloud, triangles, point images) is displayed. With the button displayed next to them, these elements can be deleted completely after confirmation.

Under Dimensions the corner coordinates of the object area are specified, for processings such as rectifications, image mosaics or 3D visualisations. With the button Calculate the minimum and maximum coordinate values of the stored object coordinates are calculated.

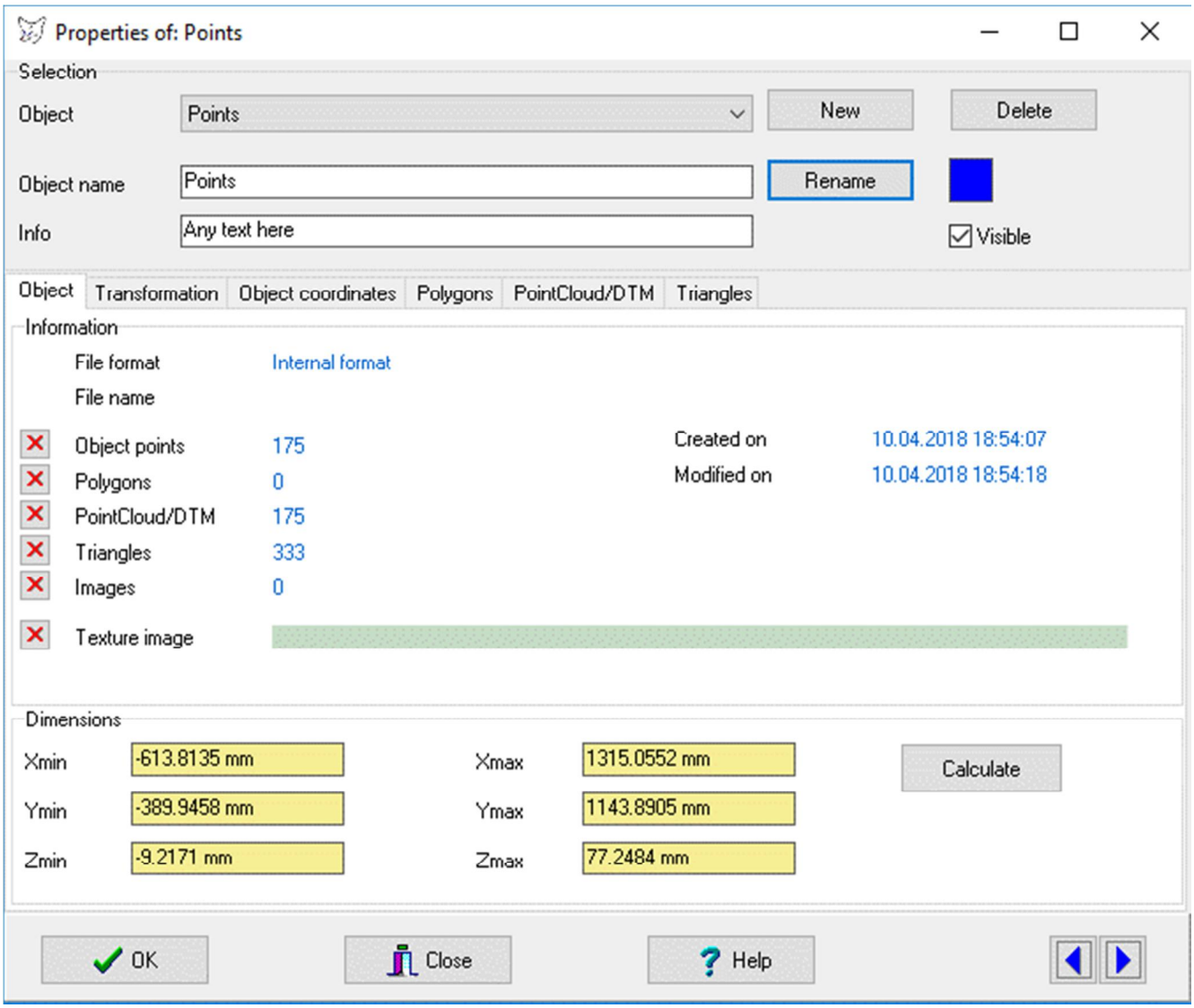


Fig. 88: Object: Object properties

9.1.2 Transformation

On the page **Transformation** parameters of a 3D coordinate transformation can be specified. In addition, the calculated parameters of a best-fit element belonging to the object can be displayed.

Under *Source object* the object is selected which transformation parameters will be displayed below. With Assign transformation the seven entered parameters of a 3D transformation are stored for the object selected under *Target object*. Under *Rotation matrix* the rotation matrix of angles ω,φ,κ is shown. The button Transform object points is used to transform the object coordinates of the target object with the displayed parameters.

If a best-fit element is assigned to the object (e.g. as calculated under **Objects/Calculations**), the related parameters (e.g. *a*, *b*, *c*, *d* of a best-fit plane) are displayed. They cannot be edited.

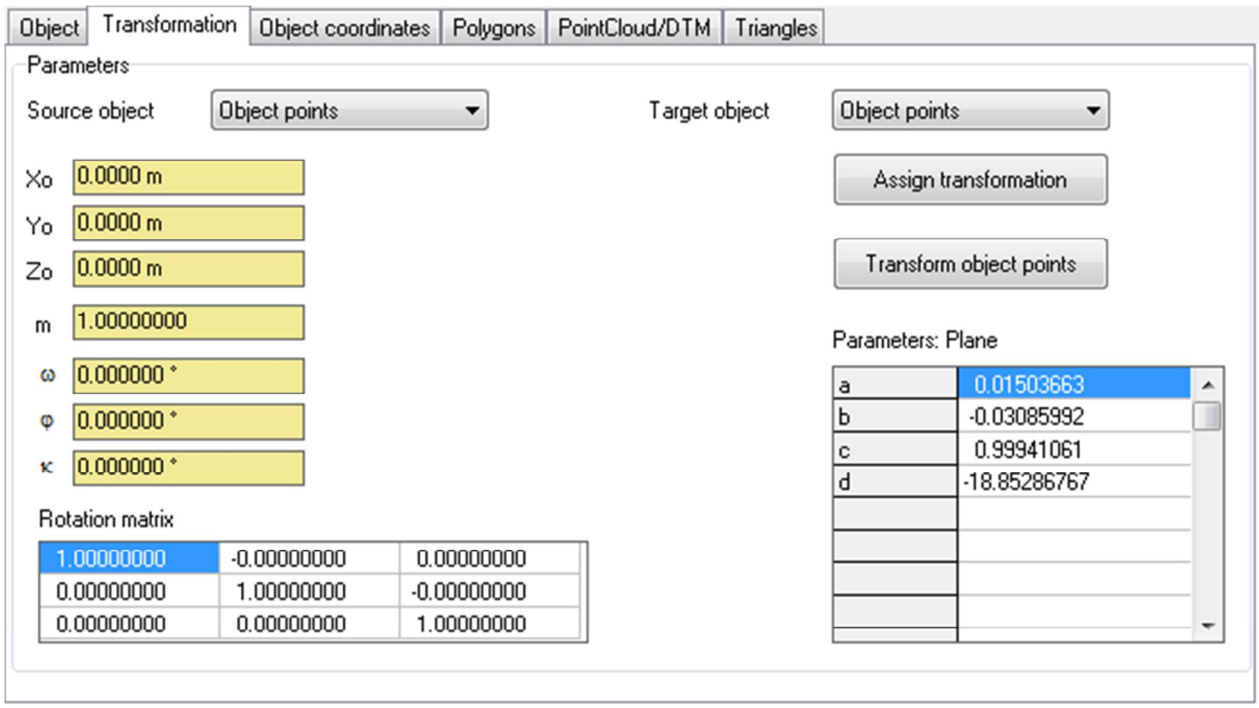


Fig. 89: Object properties: Transformation

9.1.3 Object coordinates

The page **Object coordinates** manages the object points stored to the current object. The check box ☑ specifies whether the point is active. Non-active points are suppressed in different calculations and in graphical outputs. In addition, stored standard deviations and timestamps can be displayed to the object points. The coordinates are listed in the physical unit shown under *Unit*.

By default maximum 1000 points are listed since otherwise the output of points required longer computation times. With the popup menu function **Load all points** all existing points will be displayed.

Under Style the parameters for graphic display of object point symbols can be adjusted (colour, symbol type, annotation, size). The button  opens a dialog for setting the graphics parameters.

Under Image display it can be set whether a selected object point will be shown in the open image window. The option *Current image* displays the selected points in the current image, the option *All images* displays the selected points in all open windows.

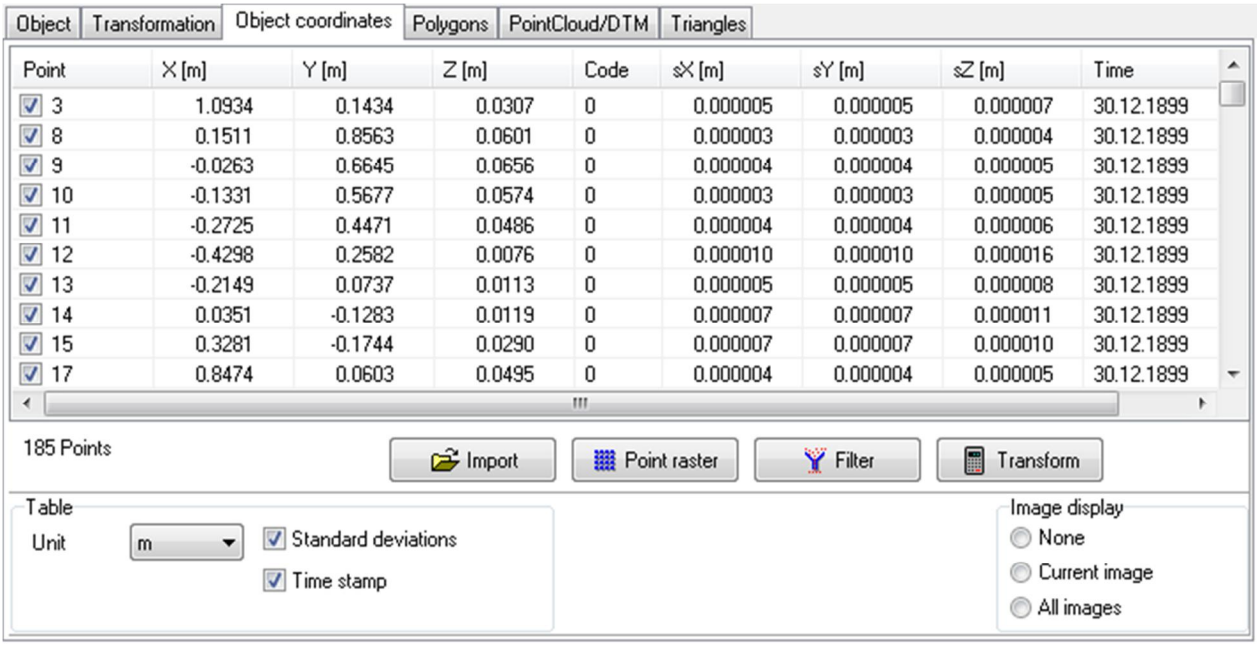
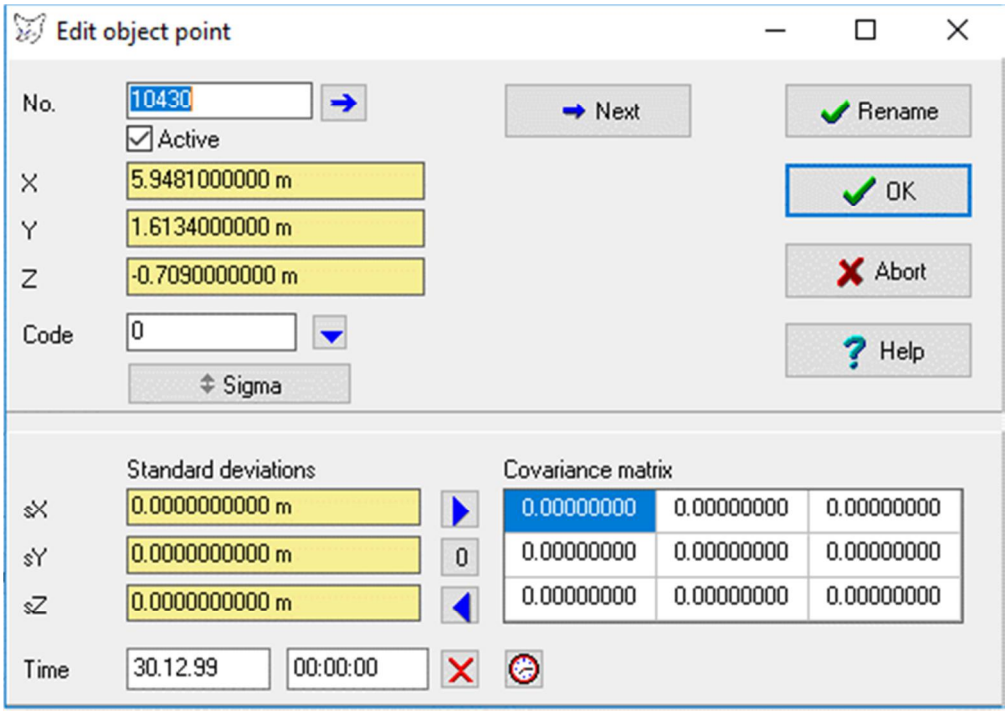


Fig. 90: Object properties: Object coordinates

The coordinates of the object are processed via the popup menu of the list with the following functions:

New To create a new point a command dialog will be displayed, where one or more points can be entered (see below)

Edit The same input dialog is shown to edit an existing point as described in **New**.



The point number is set in the *No.* field. The button → creates a new, yet unassigned number. In the *X*, *Y*, and *Z* fields any numeric values including physical unit can be entered. With *Active*, the point can be enabled or disabled.

The button Sigma extends the window for displaying standard deviations and time stamps. In the input fields for *sX*, *sY*, and *sZ* any numeric values including physical

unit for the standard deviations or uncertainty of measurement of the coordinates can be entered. The button 0 resets all values to null. Under *Time*, date and time of a point measurement can be set. The button ✕ resets these values to zero, the button to the current time.

The button Next stores the entered point and generates the next free number. With Rename the current point is renamed and the dialog is closed. The button OK also saves the data and closes the window. With Cancel the dialog is closed without saving.

Delete All selected points of the object will be deleted after confirmation.

Copy All selected points are copied to an internal cache which will be cleared when the window is closed.

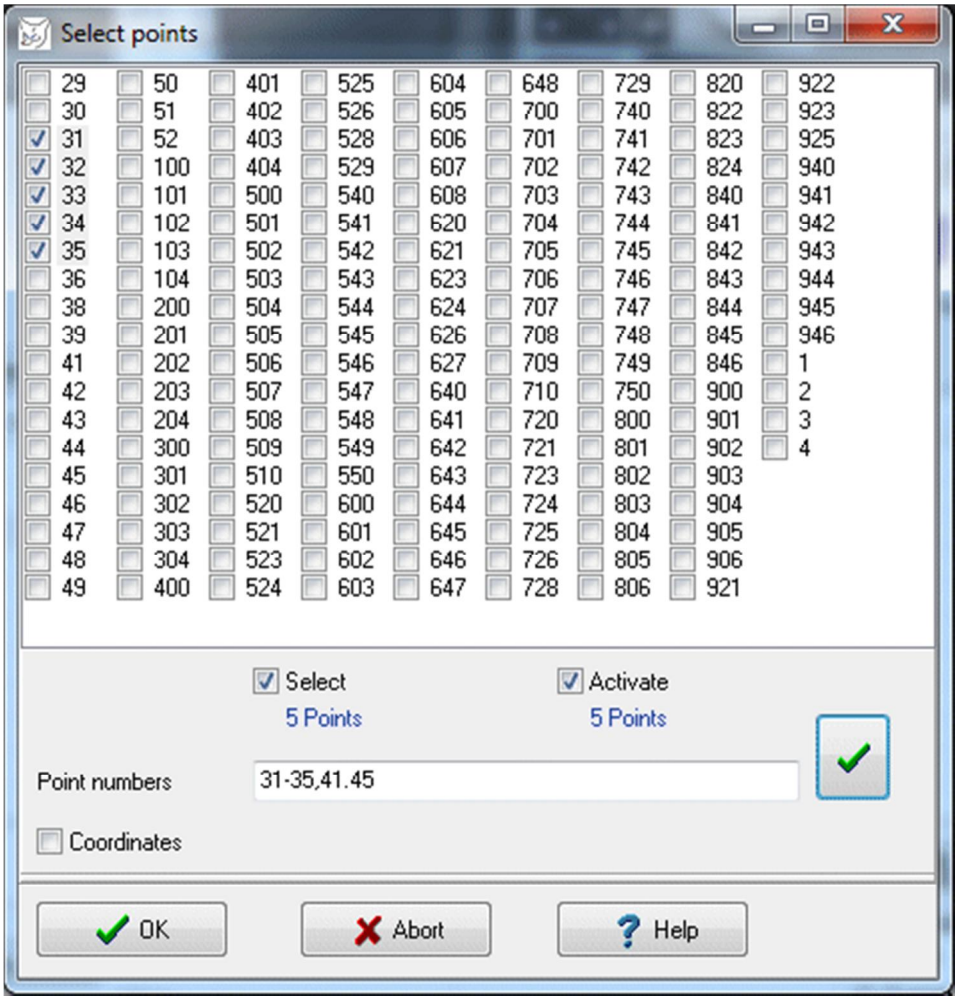
Paste All existing cached object points are copied to the current list. Double point numbers may occur after inserting.

Load all points All existing points will be displayed

Select all Selection of all points of the object

Toggle selection Inverse the selection

Point selection Opens a dialog in which individual points can be selected:



Select: Selects the point which match the conditions

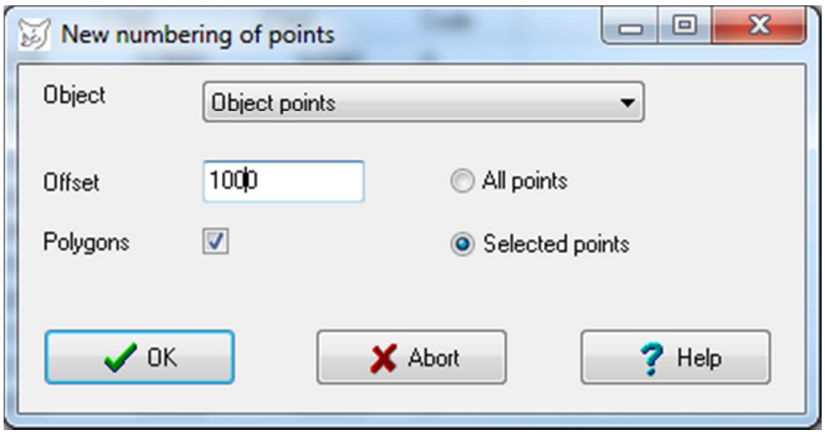
Activate: Activates the point which match the conditions

Point numbers: Input of point numbers

Coordinates: Expands the window for the input of minimum and maximum coordinates and/or point code

Sort Arranges the coordinate list as it appears in the window. The display can be modified by clicking on the column headings.

New point numbers Opens a dialog in which an offset to all selected point numbers can be entered:



Negative offsets are possible as long as no negative point numbers arise. The option *Polygons* controls whether the point allocation of existing polygons should be adapted to the new point number. *All points* or *Selected points* can be to transformed.

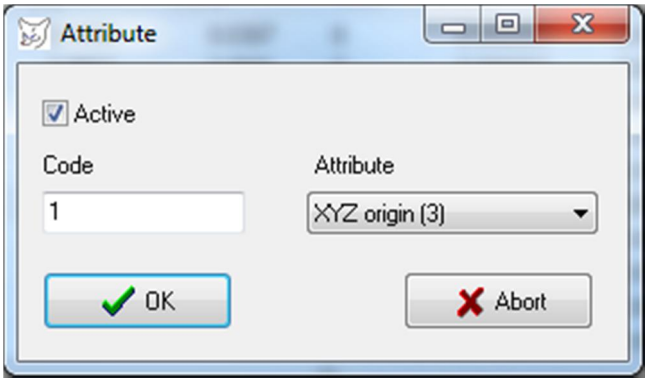
Points to polygon All marked points are mapped to a new polygon which can be displayed and edited on the page *Polygons*. The order of the polygon points corresponds to the order in the object list.

Point to point cloud Copies all selected points into the point cloud associated with the object.

Points to distances New polygons are created between all possible pairs of selected points in order to define a distance objects with 2 points.

Transform points All selected points can be transformed with the function **Objects/Transform**, for example, into a new physical unit. The function can be directly called with the button Transform.

Attributes A dialog is opened where the default point codes can be selected.



Copy table Copies all the selected points in Excel format to the Windows clipboard.

Reset standard dev. Sets all standard deviation of the selected points to zero.

With the button Import 3D object coordinates can be read from external files. The function corresponds to the menu item **Project/Import/Object elements**.

The button Point raster opens a dialog in which a regular grid of points can be generated. For each X-, Y- and Z-direction a minimum and a maximum value and a grid spacing *Delta* are entered for the generation of the new points. A *Delta* of zero creates no points in the respective direction so that it is possible to generate one -, two - or three-dimensional point distributions. The generated point grid starts with the entered point number. The option *Point cloud* controls whether the generated 3D points are stored in a point cloud structure. The order of points in the point cloud derives from the defined *Data structure* (see also page *Point cloud*).

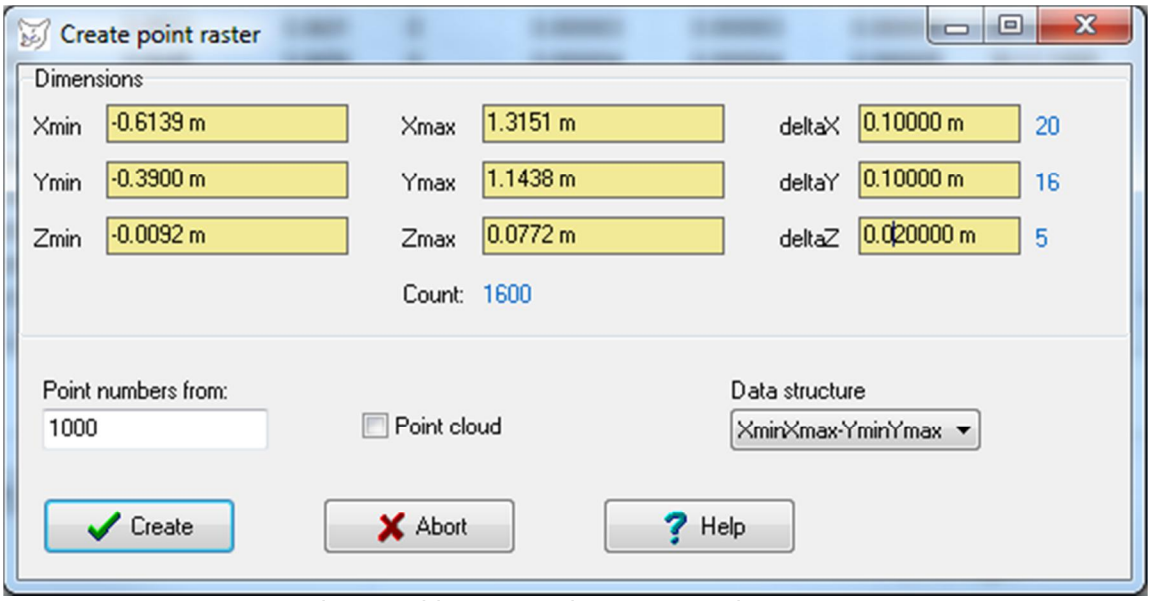


Fig. 91: Object properties: Create point raster

The button Filter opens the dialog of function **Object/Filter** for the filtering of object points.

The button Transform invokes a dialog regarding the transformation of coordinates with the function **Objects/Transform**.

9.1.4 Polygons

On the page **Polygons** polygons are created and managed with the points stored in object coordinates. Polygons are just topological connections between points, for example the representation of point-to-point connections or object surfaces. When polygons are closed, the first and last points are the same.

Under Style the parameters for graphic display of the current polygon can be adjusted (line colour, fill pattern, line width). The button  opens a dialog for setting the graphics parameters.

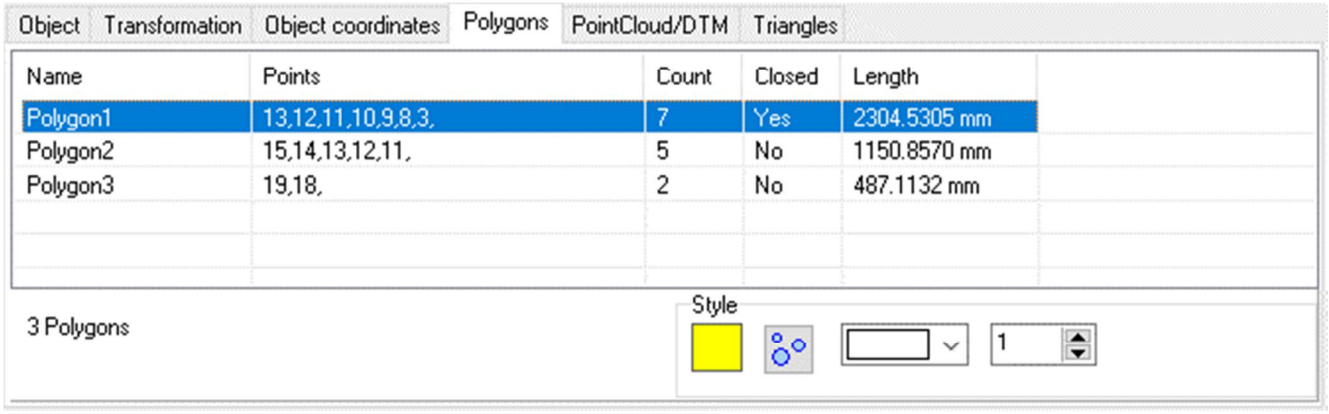
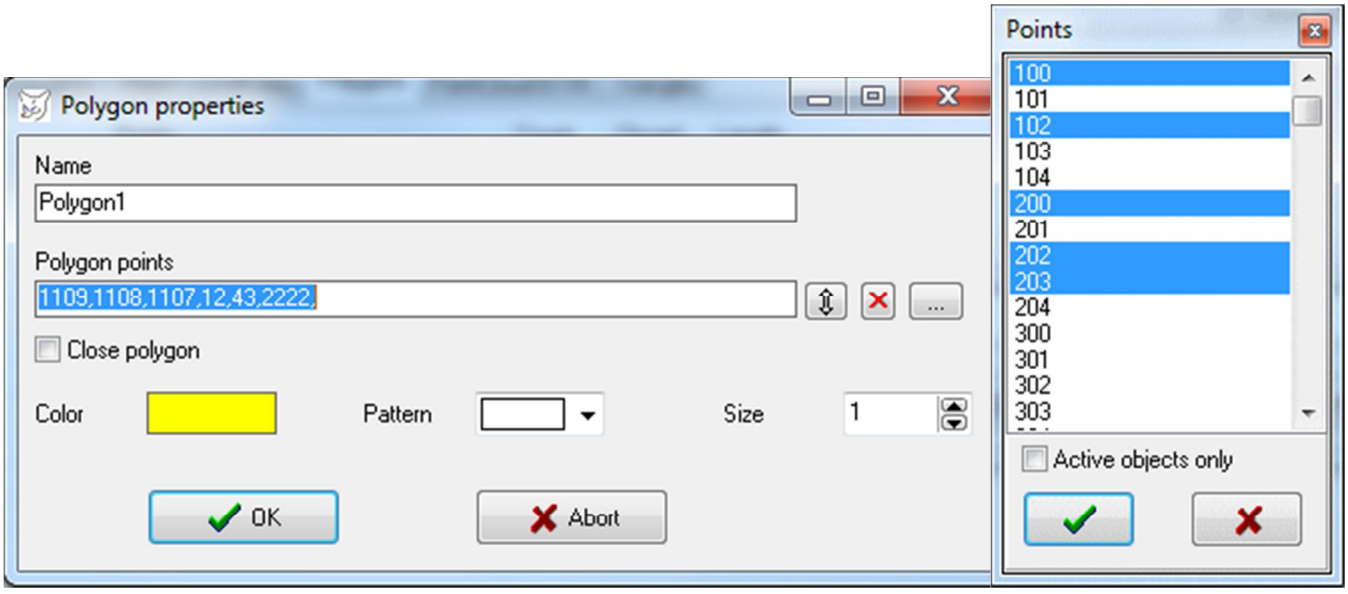


Fig. 92: Object properties: Polygons

The polygons are processed via the popup menu of the polygon list with the following functions:

New	For generating a new polygon, an input dialog will be shown, in which point numbers of polygon points be entered (see below).
Edit	The same input dialog as for **New** is shown to edit an existing polygon.
Copy	All selected polygons are copied to an internal cache.
Paste	Polygons from the cache are copied into the current object.
Delete	Deletes all selected polygons after confirmation.
Select all	Selection of all polygons
Toggle selection	Inverts the selection



a) editing polygons b) selection of object points

Fig. 93: Object properties: additional dialogs for polygons

The dialog above is opened for editing a polygon. In the *Polygon points* input field, the sequence of point numbers is entered, separated by comma. It corresponds to the order in which the polygon points are connected to each other. The button ⇳ reverses the order of points. The button … opens a point selection

window (see figure b above), in which one or more existing points can be selected. With OK the input is confirmed and the data are stored.

Close polygon	Closes the polygon, i.e. the first and last points are connected to each other
Color	Line and fill color of the polygon
Pattern	Fill pattern (no fill is the second pattern of the list)
Size	Width of the polygon line

9.1.5 Point cloud/DTM

On the page Point cloud/DTM unnumbered object coordinates can be managed. Under point clouds/DTM, here any number of object points (point clods or digital terrain models) without number are understood, which are sequentially stored.

Optionally, the data can be structured in a grid to form a digital terrain model (DTM). In this case, the point order is set according to the settings under *Data structure*.

The colour of the displayed point cloud can be adjusted by the colour panel. The button  opens a dialog for setting graphics parameters to display the current point cloud.

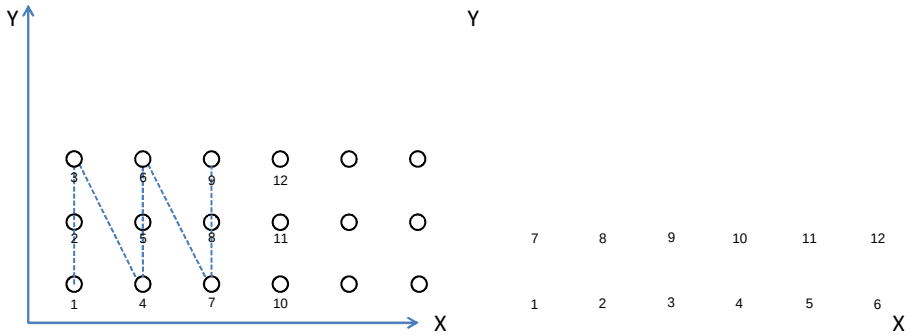


Fig. 94: Data structure of object points of a DTM

Under Properties the structure of the existing object points is displayed.

File name	Name of the file from which the point cloud has been read.
Format	The point cloud format: *XYZ*: the data contain the XYZ coordinates of the object points *Z*: the data contain only the Z-coordinates of object points, X and Y arise from the grid spacing of the points *XYZ_RGB*: The data contain the XYZ coordinates of the object points as well as an RGB color value per point
Data structure	Organization of the points in a regularly built DTM (see figure above)
Number of points	Number of points in X- or Y-direction if the scatter plot should have a regular grid structure.

Raster width X/Y Distance of the points in X- or Y-direction if the point cloud has a regular grid structure and only Z values have been read.

Count in X/Y Number points in X- or Y-direction for a DTM.

Point raster Opens the input window as described under Object coordinates .

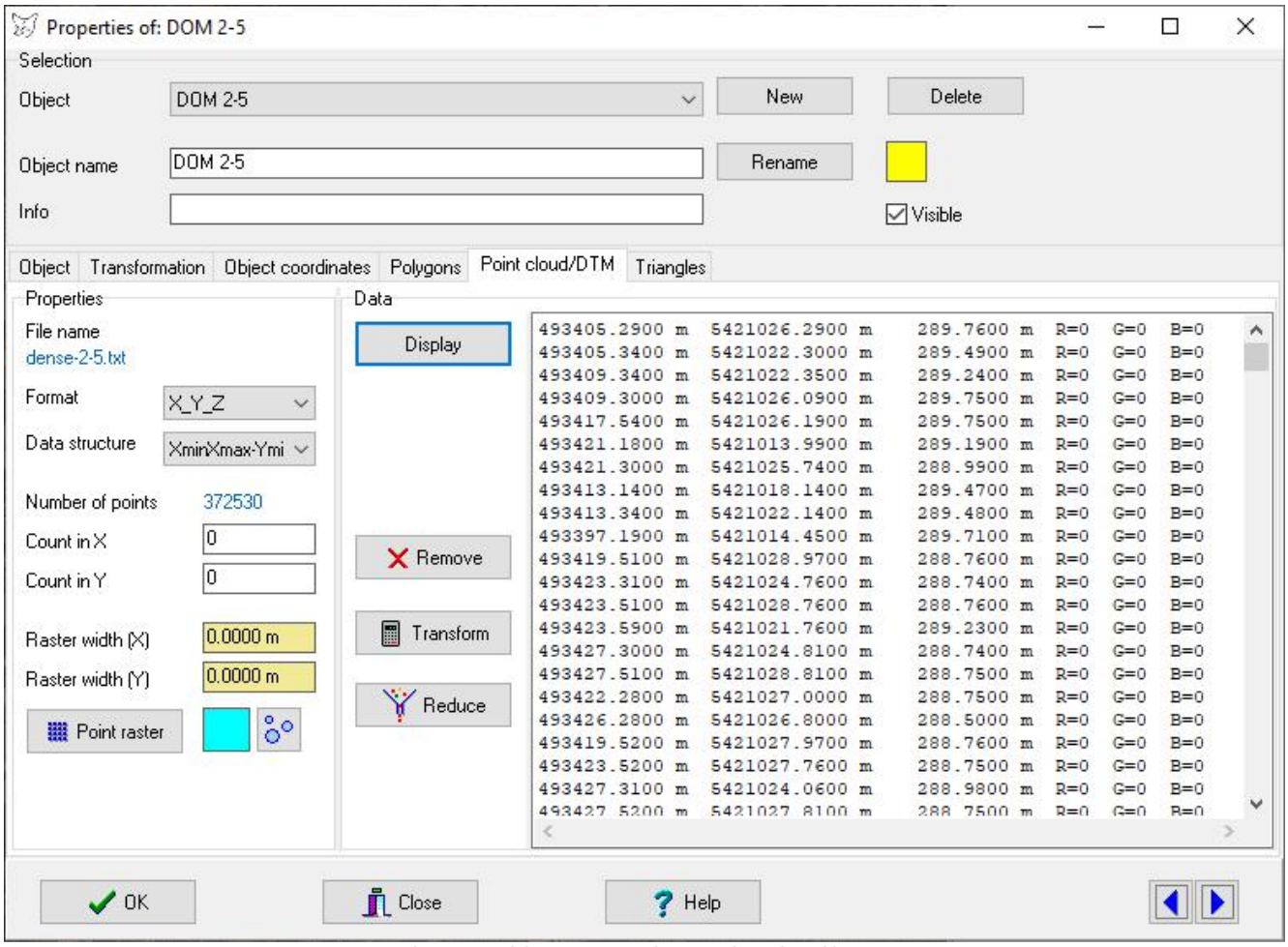


Fig. 95: Object properties: Point cloud/DTM

Under Data the point cloud / the DTM can be read and displayed.

Display Displays the point coordinates in the right text box (may lead to overflow)

Remove Removes the point cloud from the current object

Transform Call to the function **Objects/Transform**

Reduce The point cloud with n points will be reduced by the entered factor p, i.e. n/p points will remain.

Import and export of point clouds is done via the menu functions **Project/Import/Point cloud** resp. **Project/Export/Point cloud**.

9.1.6 Triangles

On the page **Triangles** data of a triangulated irregular network (TIN) or mesh can be managed.

Under Properties general information is displayed.

Triangles Number of stored triangles

Xmin, Ymin, …. Minimum and maximum coordinates of the points of the TIN

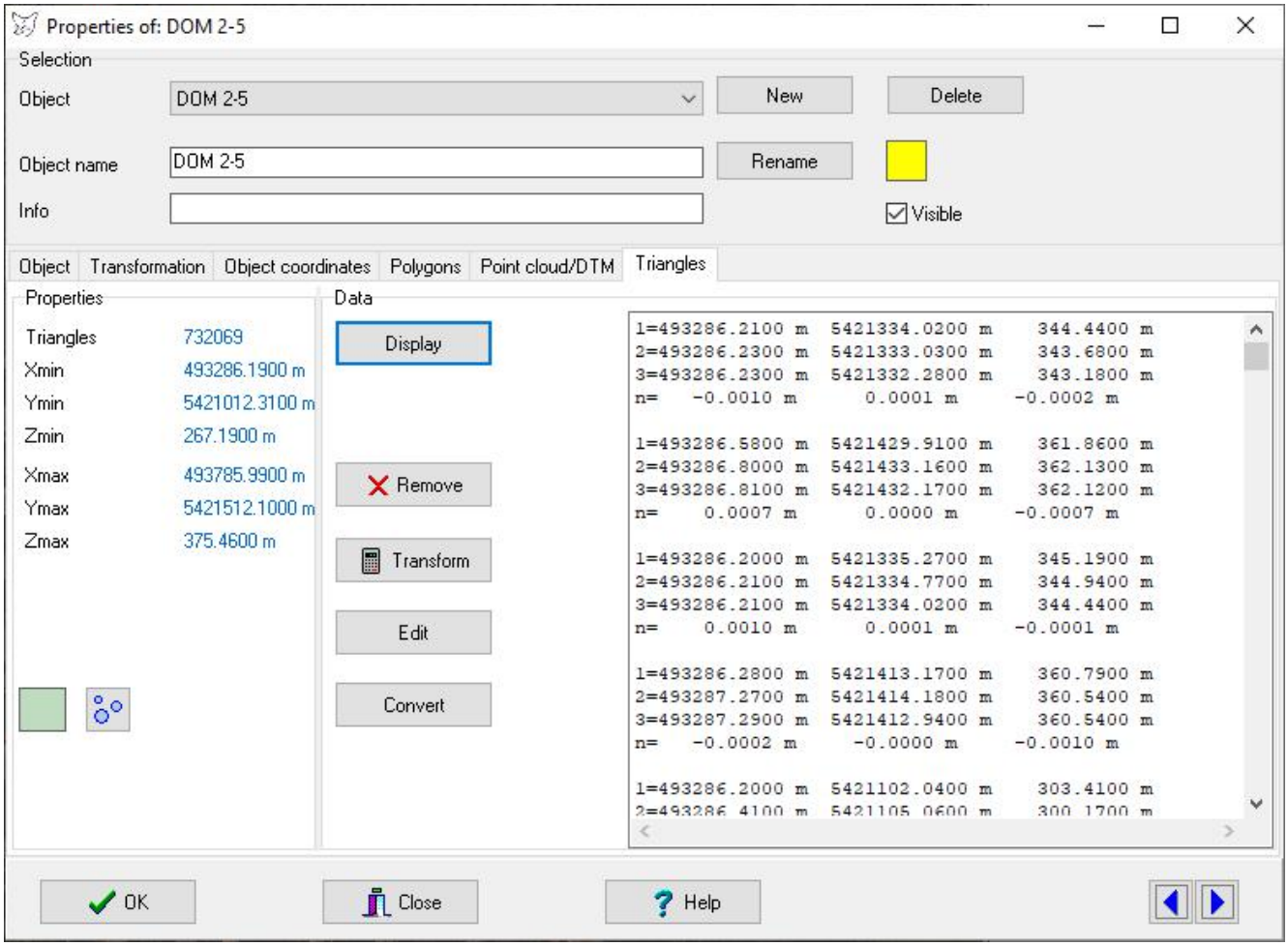


Fig. 96: Object properties: Triangles

Under Data the stored triangles can be read, viewed and changed.

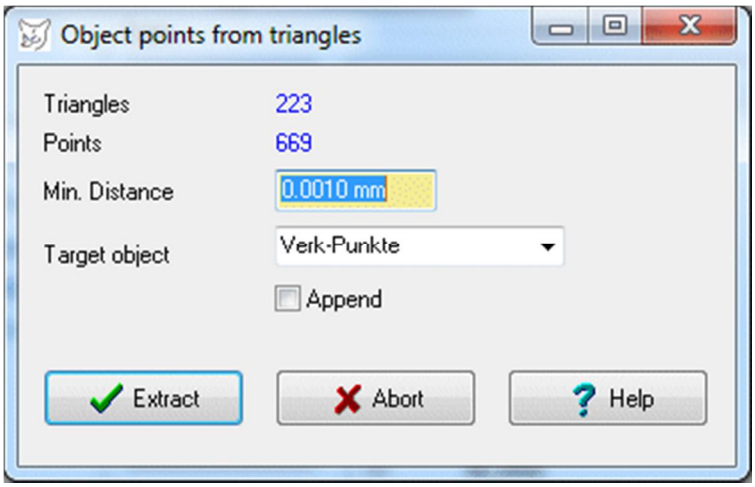
Display Displays the point coordinates of all triangles in the right text box

Remove Removes the triangles from the current object

Transform Call to the function **Objects/Transform**

Edit Lists the existing triangles with their individual area. They can be deleted or their points can be reversed via the popup menu.

Convert Invokes the following window where all triangle points can be converted to object points:



The number of *Triangles* and *Points* is displayed. *Min. Distance* defines the minimum distance between triangle points so that they are separated as individual points. Under *Target object* the object is defined where the new points are stored,
With Extract the points are created. Abort closes the window without creating points.

The colour of the displayed triangles can be adjusted by the colour panel. The button opens a dialog for setting graphics parameters for the display of the triangles.

Import and export of point clouds is done via the menu functions **Project/Import/Triangular mesh** resp. **Project/Export/Triangular mesh**.

9.2 Polygons

Menu:	Objects→ Polygons
Precondition:	Loaded project and existing object

The function **Polygons** is used for creating polygons from existing 3D-object coordinates. A docking window opens in which polygons are created or selected and the corresponding points are defined. The measurement of object points can only be done under **Measure/Object coordinates**.

Under Selection polygons are created, deleted, or selected. With the button the selected polygon can be closed or opened. The button opens a dialog for setting graphics parameters for the display of the selected polygon. With double-click on the name of the polygon, the dialog for Object properties is displayed. The selected polygon is shown in all open image windows.

Under Object the associated polygon point numbers are listed in the order of point connections. The order can be changed using the two arrow buttons shown below the list. The button reverses the order of points. All

points to the currently selected object are displayed in the right list. They can be marked and transferred to the polygon points list with the button .

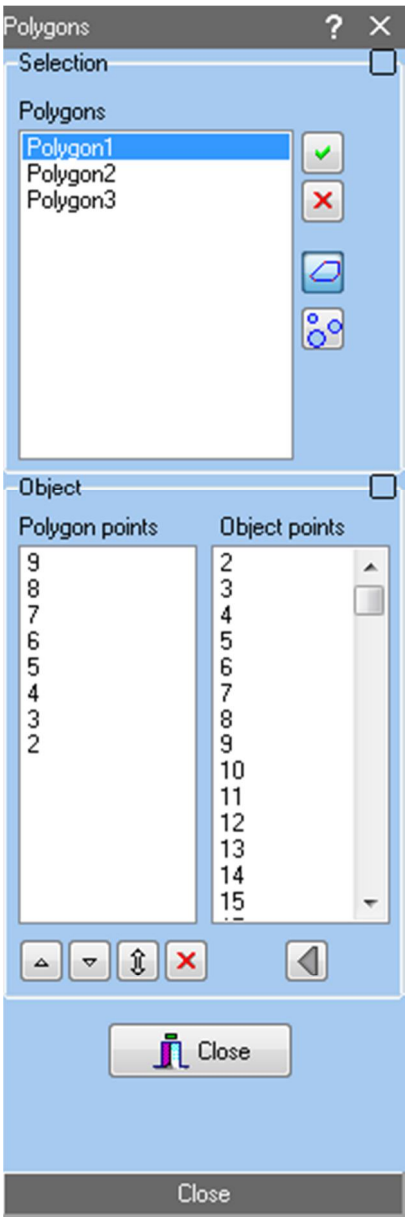


Fig. 97: Docking window for the definition of object polygons

Polygon points can also be added by clicking an object point with the mouse within the current image. The cursor has the shape of a lasso.

9.3 Transform

Menu:	Objects → Transform
Precondition:	Loaded project and existing object

The function **Transform** is used to transform the coordinates of object points, point clouds or triangles of the current object, or the exterior of one or more images, respectively.

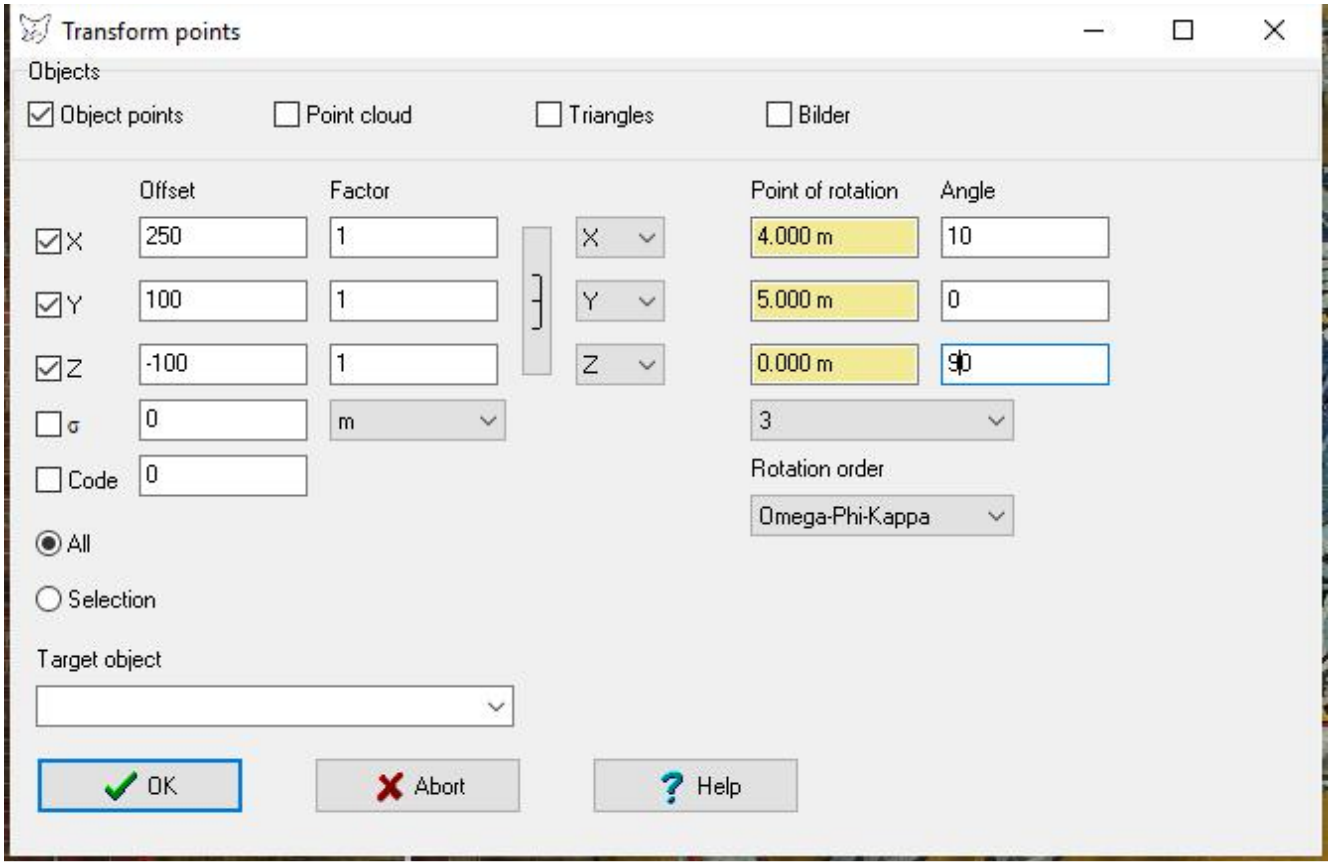


Fig. 98: Transformation of object points

The selected Objects can be shifted (*Offset*), scaled (*Factor*) or rotated around a *Point of rotation* with *Angle*. In addition, a standard deviation σ can be assigned to the object points, and points coordinates can be converted into another unit. If a *Target object* is specified, the transformed coordinates are stored with this (new) target object.

The rotation is carried out around the coordinates displayed under *Point of rotation*. Preset point coordinates can be selected from the list, e.g. origin of the object coordinate system, centroid of object points, or an explicit point of the object. The entered angles correspond to the rotations about the X-, Y-, and Z-axis and are converted into an appropriate rotation matrix with the selected *Rotation order*.

If the function was called through the window **Objects/Object properties/Object coordinates**, selected points can be transformed if they were marked in the list of object points. For point clouds and triangles all points are used.

For images, either all images (*All*) or the current image (*Selection*) will be processed. In that case the translation parameters of exterior orientation will be shifted by Offset and scaled by Factor. The rotation angles of exterior orientation are rotated by angle, hence the input of zero does not change the rotation. As point of rotation always the position of exterior orientation is used. A new order of rotation can be activated. The transformation of exterior orientation into other physical units can also be conducted under **Images/Properties/Transformations**.

With Ok the points are transformed and assigned to the object specified in the target object. If the name of a non-existing object is entered, it will be created. If existing point numbers exist in the target object, they will be overwritten.

9.4 Calculations

Menu:	Objects → Calculations
Precondition:	Loaded project and existing object

The function **Calculations** is used for calculating mathematical functions between 3D points.

Under Object the desired 3D object is selected, whose stored 3D points are displayed in the list. Selected points will be used for the subsequent calculation. Different calculations require certain attributes of object points that can be defined by the popup menu function **Attributes**.

Under Calculation the mathematical calculation function can be selected. Currently the following functions are implemented:

Centroid Calculates the centroid (center of gravity) from the selected points. The number of selected points is arbitrary. The calculated point will be shown under *Result*.

Distance Calculates the distance (Euclidean distance) between two points. Exactly two points must be selected. The computed coordinate differences are displayed under *Result.*

Foot point Calculate the foot point of a point with the attribute Point3 (code 10) along the straight line between two points with the attributes Point1 (code 8) and Point2 (code 9). Exactly three points must be selected. The calculated coordinates as well as the distance of Point 3 to the straight lines appear under *Result*.

Angle between 2 straight lines Calculates the angle between two straight lines. The first is defined by the points with the attributes Point1 and Point2, the second straight line runs through the points with attributes Point3 and Point4. The calculated angle will be shown under *Result*. In addition to the spatial angle the angles projected into the XY, XZ and YZ coordinate planes are calculated.

Best-fit plane Calculates a best-fit plane for the selected points. At least three points must be selected. The calculated standard deviation *Sigma*, of the plane parameters *a*,

b, *c*, *d* and a point in the plane (centroid of the points projected into the plane) are shown under *Result.*

Under Result the new calculated point appears. Not every function calculates a new point, occasionally other calculation results are displayed. The displayed point number corresponds to the next free number, it can be changed as desired. The XYZ values are presented in the currently selected length unit.

With Save the point data is stored to the object specified under *Output*. If a best-fit element has been calculated, the corresponding element parameters are also stored to the output object. In addition, all entry points (observations) for the best-fit calculation are projected onto the adjusted element and stored as new points in the output object.

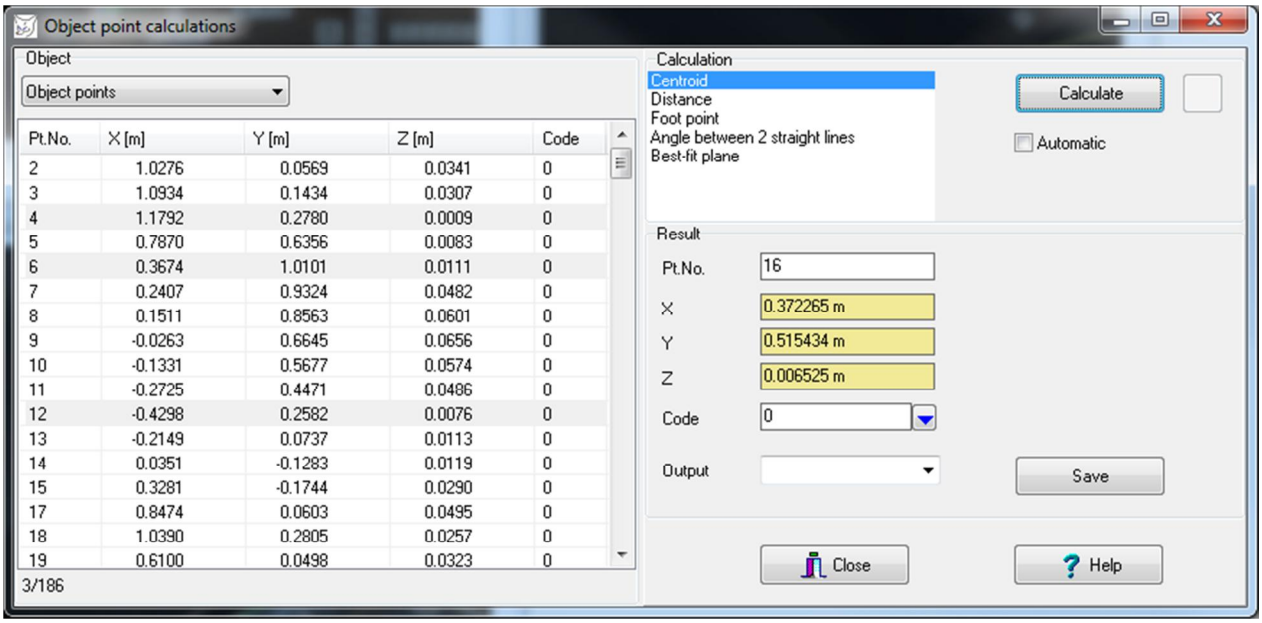


Fig. 99: Calculations with 3D points

9.5 Elements

Menu:	Objects → Elements
Precondition:	Loaded project and existing object

The function **Elements** is used for calculating 3D points based on geometric elements, for example along a straight line or a circle in space. Metric values are entered in the current unit for object coordinates.

Under Object the current object is selected to be associated with the newly created geometry elements. The calculations can optionally be conducted with the stored object Data (*object points, point cloud* or *triangles*). The button creates a new object, if the name of a non-existent object box is entered.

Under Elements the desired calculation function is selected. A number of optional parameters belong to each function. Following geometric elements can be selected:

Point Accepts the specified coordinates under *Circle center* as a 3D point.

Perspective center Takes the coordinates of the projection centers of the selected images as 3D points.

Centroid Calculates the center-of-gravity of the current object (for *object points* or *point cloud*).

Circumscribing box Calculates the eight vertices of the smallest bounding box of the current object (for *points*, *point cloud* or *triangles*).

Cube Calculates the eight vertices of parallelepiped with the object coordinates specified under *Cube* (for *object points*, *point cloud* or *triangles*).

Straight line Calculates a number of 3D points along the line between point 1 and point 2 (for points) with a specified *Point spacing*.

Triangle Creates a spatial triangle the triangle height *Radius* and the base side 2tan(*Angle* / 2), as well as the Z-dimension *Height*.

3D circle Calculates a number of 3D points on a circle in space with the selected *Center* coordinates and the specified *Orientation* angles in a selectable *Radius* (for *points*) and an angular distance of *Angle*.

Sphere Calculates a number of 3D points on a sphere with the selected *Center* coordinates and the specified Radius (for *points*). On the sphere, the point difference is determined by the specified *Angle* with 1 <= α <= 90°. *Height* is the vertical angle with 0 <= β <= 180° specifying the completeness of the sphere. At an angle of 180°, a full sphere, at 90° is a hemisphere is created.

Cylinder Calculates a number of 3D points on a cylinder with the selected *Center* coordinates, the specified *Radius* and *Height* (for *points*). On the cylinder, the point distance is determined by the given inner *Angle* with 1 <= α <= 90°.

Cone Calculates a number of 3D points on a cone with the selected *Center* coordinates, the specified *Radius* and *Height* (for *points*). The point interval on the base circle of the cone is determined by the given inner *Angle* with 1 <= α <= 90°.

Paraboloid Calculates a number of 3D points on a rotational paraboloid with the selected *Center* coordinates, a given *Radius* r and the focal length f (for *points*). The Z-coordinates of the points are calculated after $Z = a \cdot r^2$, where $a = 1/(4 \cdot f)$. The point interval on the base circle of the cone is determined by the given inner *Angle* with 1 <= α <= 90°.

Point raster Calculates a number of 3D points in a regular three-dimensional grid with the selected *Dimensions* and point intervals *Delta* (for *points*).

Sinusoidal surface A number of 3D points in a regular three-dimensional grid with the selected *Dimensions* and point intervals *Delta*, where the Z value is a calculated by a double sine surface according to the formula (for points)

$$Z = 0.5 \cdot (Z_{max} - Z_{min}) \cdot \sin(2\pi \cdot \frac{(X - X_{min})}{(X_{max} - X_{min})\, p_X}) \cdot \sin(2\pi \cdot \frac{(Y - Y_{min})}{(Y_{max} - Y_{min})\, p_Y}) + 0.5 \cdot (Z_{max} + Z_{min})$$

p_X and p_Y are the specified multiples of a total period.

VDI scale bars Generates seven scale bars between the points in the specified corner coordinates according to VDI 2634. The value specified under n describes the number of points for a measurement line, generated with different intermediate distances (for *points*).

Plane Creates points in a plane (for *object points*). Three points have to be selected for which the corresponding plane parameters (*a*, *b*, *c*, *d*) are calculated. Within this plane a number of new points can be created within the dimensions for *Xmin*, *Xmax* etc.

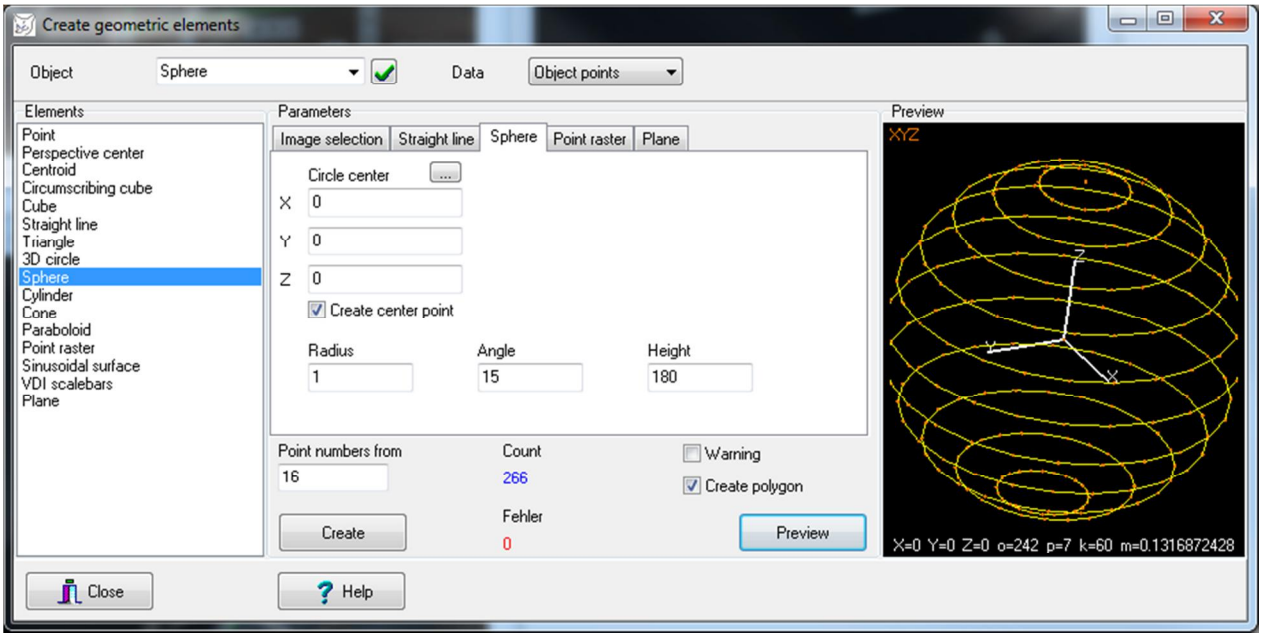
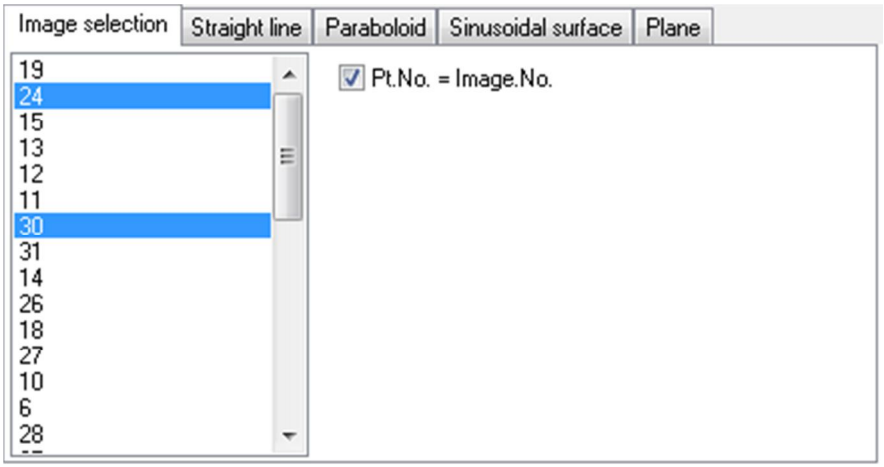


Fig. 100: Point creation by geometric elements

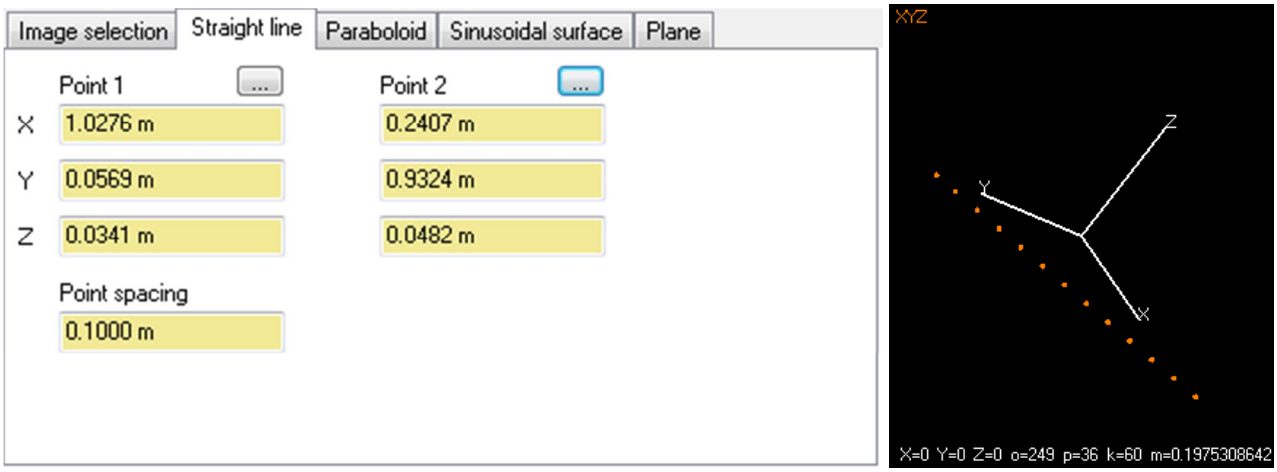
Under Parameters different options for the selected calculation function can be selected. Currently the following options are implemented:

Image selection Selection of images for the function of *Perspective centers*. If the option *Point No. = Image.No* is enabled, the 3D points receive the corresponding image number as the point number. Otherwise they will be numbered from the point number which has been defined under *Point numbers from*.



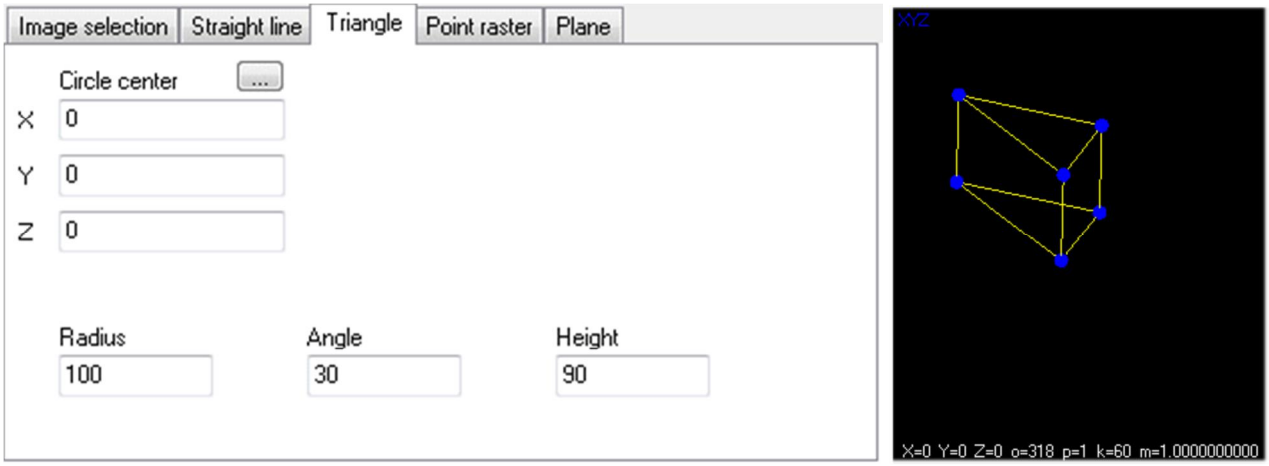
Straight line

Selection of start and endpoint of a straight line in space, as well as of the point spacing. With the buttons [...] existing 3D points can be selected as a start or end point.



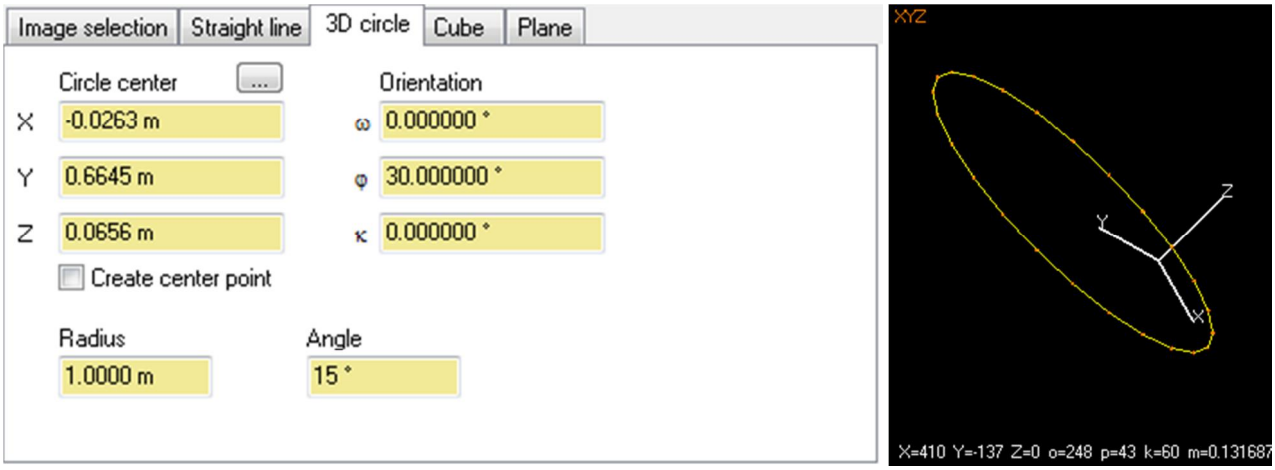
Triangle

Selection of middle point on the basic side (*Circle center*) of a triangle, with height *Radius* and the base side length of 2tan(*Angle* / 2). The Z extension is determined by the *Height* value. With the button [...] an existing 3D points can be selected as center point.



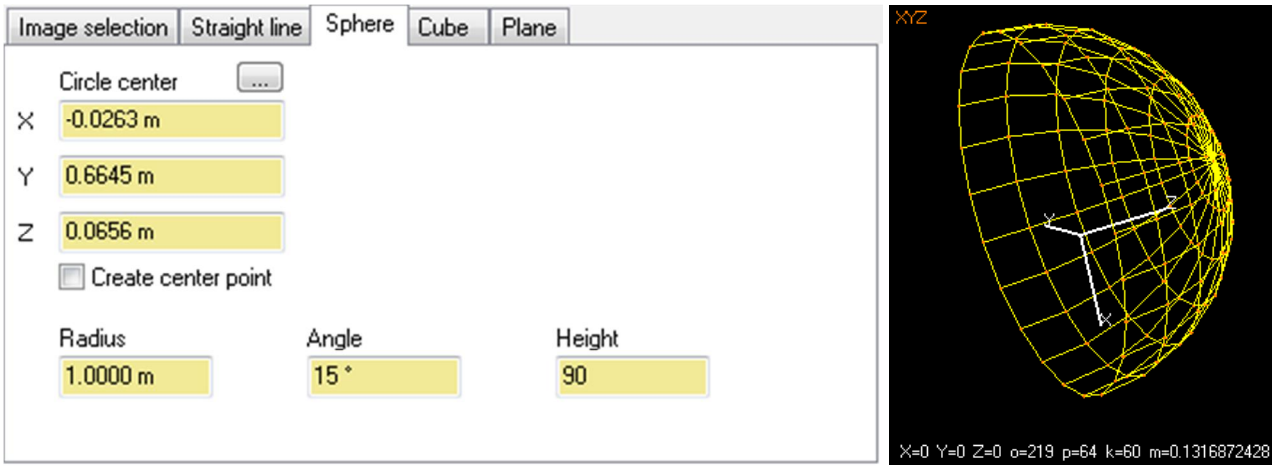
3D circle

Selection of *Circle center* and *Orientation* angles for a 3D circle with *Radius* and *Angle* (interior angles of adjacent points). With the button [...] an existing 3D point can be selected as center. *Create center point* stores the circle center as additional object point.



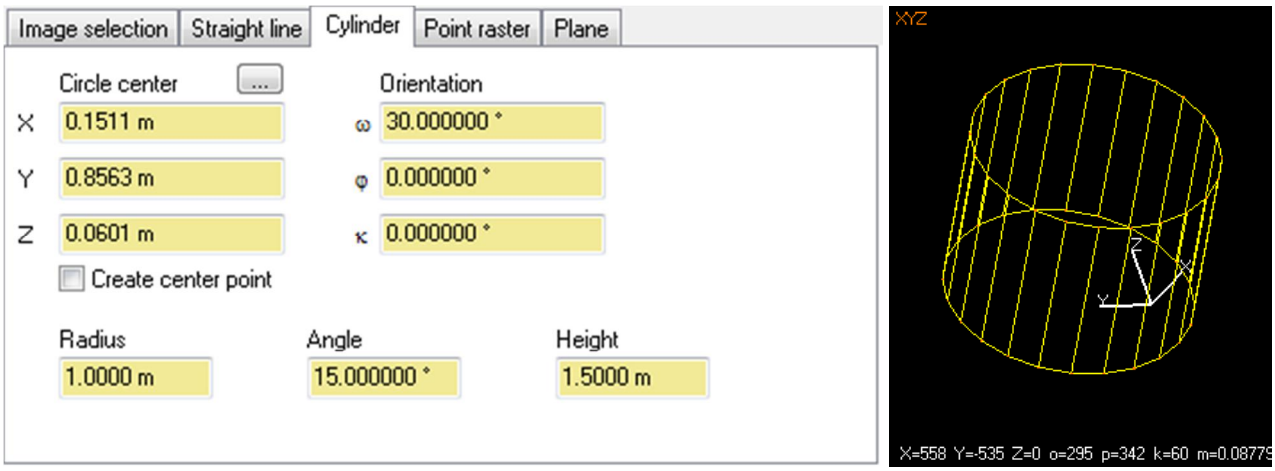
Sphere

Selection of *Circle center* of a sphere with *Radius* and inner *Angle* of the sphere points. With the button [...] an existing 3D point can be selected as center.



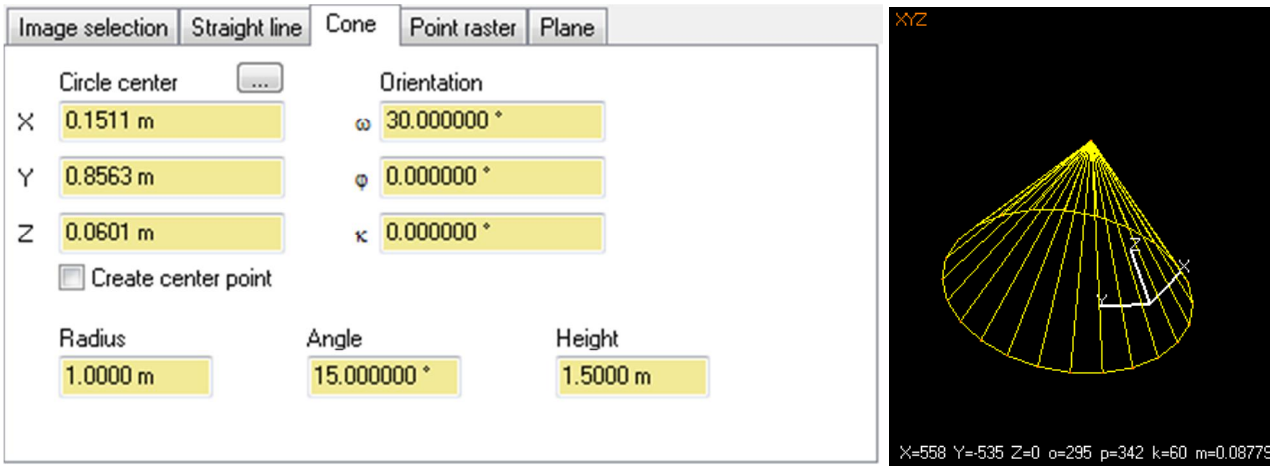
Cylinder

Selection of *Circle center* (center of base circle) and *Height* of a cylinder with *Radius* and inner *Angle* of the cylinder points. With the button [...] an existing 3D point can be selected as center.



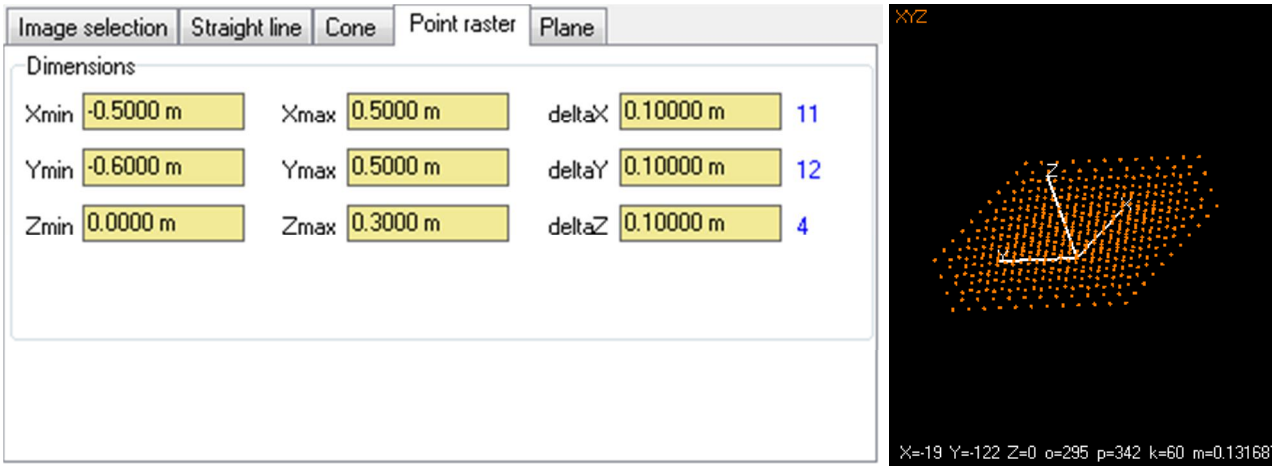
Cone

Selection of *Circle center* (center of base circle) and *Height* of a cylinder with *Radius* and inner *Angle* of the cone points. With the button [...] an existing 3D point can be selected as center.



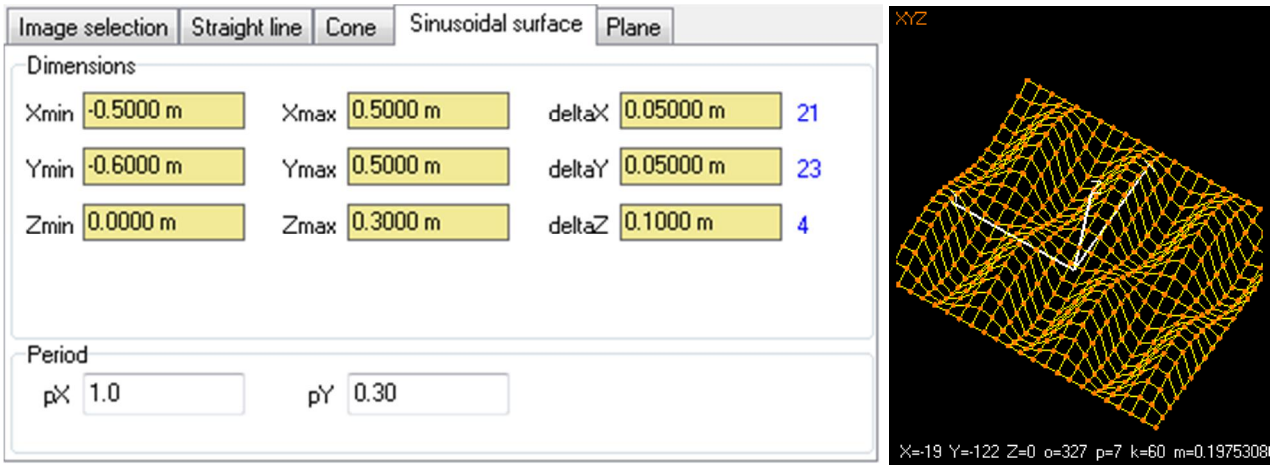
Point raster

Definition of minimum and maximum limits of the desired grid (box), as well as the respective distances *Delta* between the points. A *Delta* value of zero means that no points are created in the corresponding coordinate direction. The resulting number of points is displayed. For small deltas values, the number of created points may be very large.



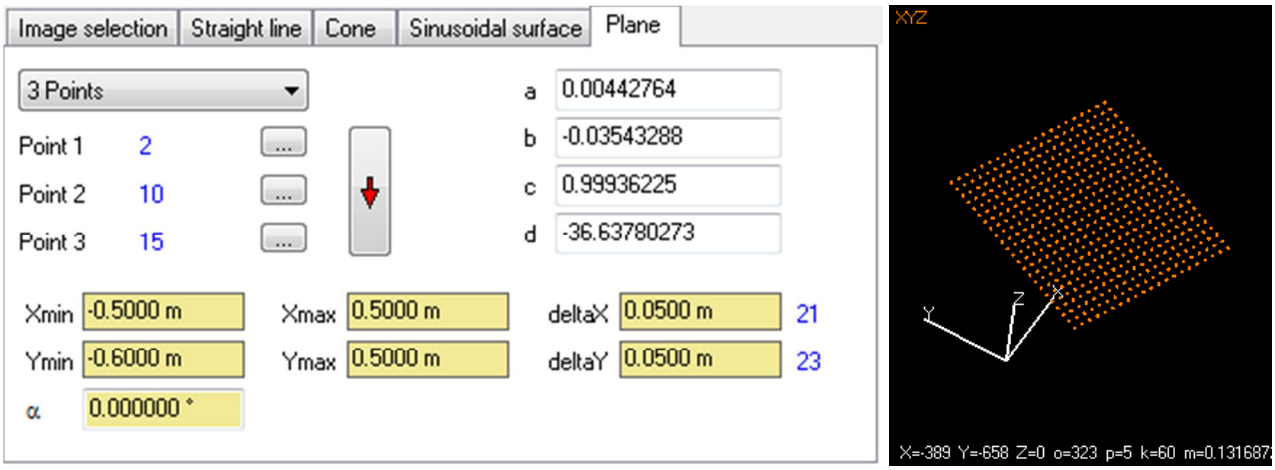
Sinusoidal surface

Definition of minimum and maximum limits of the desired grid as well as the respective distances *Delta* between the points. A double sinusoidal surface of period length *pX* and *pY* is calculated where the amplitude results of Z_{max}-Z_{min}.



Plane

The plane is defined by 3 points or an already existing best-fit plane. In both cases, three different points must be chosen (point 1 to 3), from which the plane parameters *a*, *b*, *c*, *d* are calculated, or which are projected into the plane. With the button ↓ two-dimensional dimensions of a rectangle in the plane are calculated in which the generated points lie. The origin of this grid is located in point 1 and receives the coordinates (0/0). The X axis of the rectangle is formed by the straight line from point 1 to point 2. The *deltaX* and *deltaY* values determine the point interval in the plane. The generated group of points in the plane can be rotated with the angle of α.



The switch Preview activates a 3D viewer where points and polygons of the currently calculated element can be displayed and moved. The preview function does not create or overwrites any data. A high number of calculated points (e.g. > 2000) higher computation times for 3D visualization are expected. Only with Create the 3D points are generated and saved to the current object. The numbering of the new 3D points is ascending starting with the point numbering from the entered value. If *Warning* is enabled, the user must confirm the creation of points. With *Polygons* polygons from the newly computed 3D points are created automatically.

9.6 Filter

Menu:	Objects → Filter
Precondition:	Loaded project

The function **Filter** is used for filtering images, image points, object points or triangles. For this purpose value interval for elements (e.g. point numbers or coordinates) as well as a logical conditions (AND, OR, NOT) are defined so that all elements are modified, which meet the conditions.

In the displayed pages the method selected under *Action* is carried out with Execute for those items that meet the specified criteria. At first the number of matching elements will be shown, before the action is executed after confirmation by the user. The *Activate* action activates the selected items. The *Deactivate* action deactivates the selected items. With the *Replace* action, optional new values entered in column *New values* are applied to the current items (only for standard deviations and point code). The selected items are deleted with the *Delete* action.

The button No filter resets all settings to default values.

9.6.1 Image points

The page **Image points** is used for the filtering of image coordinates.

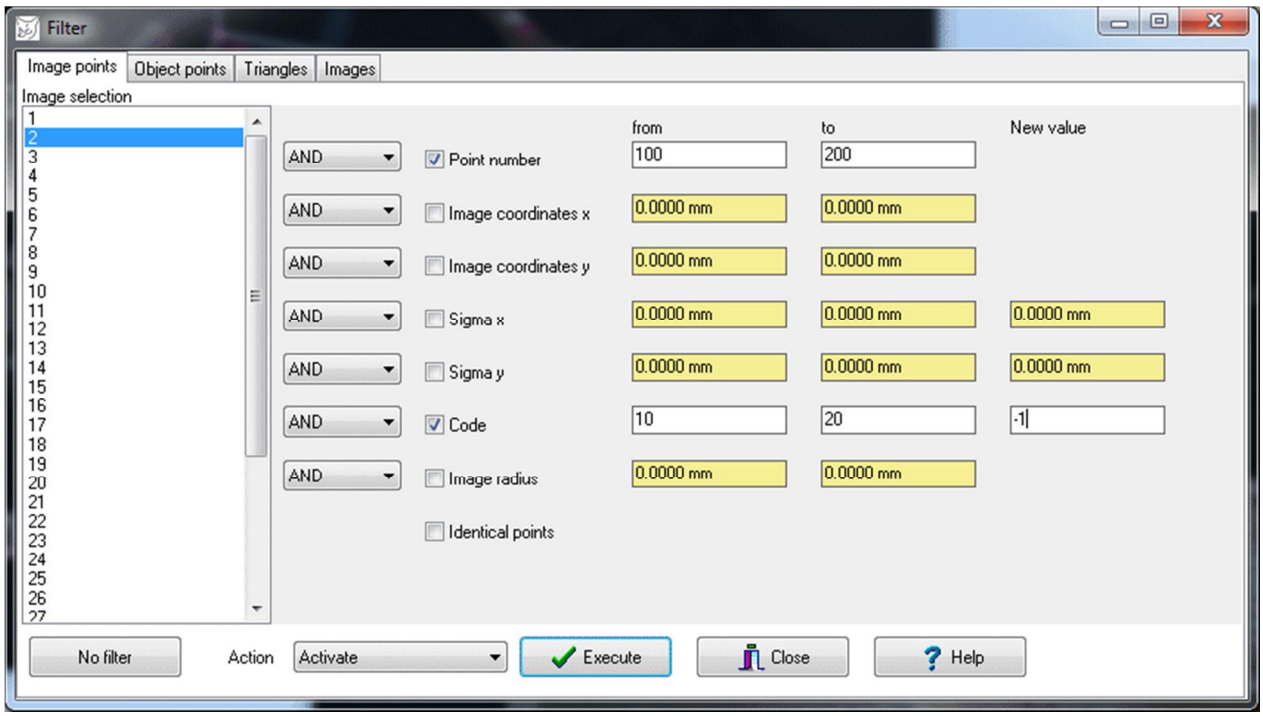


Fig. 101: Criteria for filtering of image points

Under Image selection the images are selected whose points are filtered. The related popup menu allows for the selection of all images.

The value intervals and logical conditions are set in the right side of the window. The following filter criteria are implemented:

Point number	Selection of specific point numbers (integer)
Image coordinates	Selection of image coordinates in x or y
Sigma	Selection of points with a particular standard deviation in x or y; a new value can be assigned to the selected points
Code	Selection of points with a certain code; a new value can be assigned to the selected points
Image radius	Selection of image coordinates that are in a certain distance from the principal point
Identical points	Selection of image points that are identical over all selected images; this function cannot be combined with the above listed criteria.

In the example above, the action *Activate* selects and activates all points of image 7 whose point number is between 100 and 200 and whose point code is between 10 and 20. The *Delete* action removes these points from the image. With the Replace action all points with codes between 10 and 20 will get the new value of -1.

9.6.2 Object points

The page **Object points** is used for the filtering of object points.

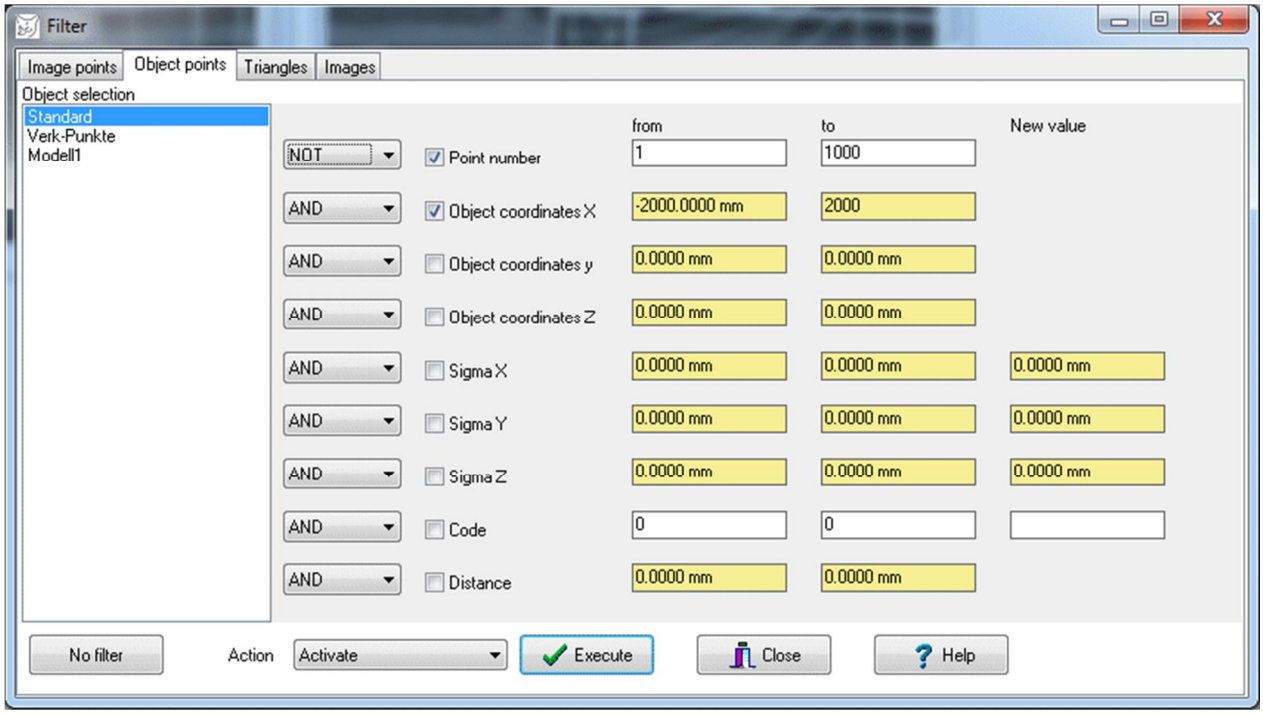


Fig. 102: Criteria for filtering of object points

Under Object selection the objects are selected for which points shall be filtered. The popup menu allows for the selection of all objects.

The value intervals and logical conditions are set in the right side of the window. The following filter criteria are implemented:

Point number	Selection of specific point numbers
Object coordinates	Selection by object coordinates to X, Y or Z
Sigma	Selection of points with a particular standard deviation in X, Y, or Z; a new value can be assigned to the selected points
Code	Selection of points with a certain code; a new value can be assigned to the selected points
Distance	Selection by object coordinates that are at a certain distance from the origin

In the above example, all points of the object will be selected and activated with action *Activate* if their number is not be between 1 and 1000 and the object coordinates in the X direction range from 2000 to +2000. The *Delete* action removes these points from the object. With the *Replace* action, nothing happens in this example. The *Deactivate* action disables all points that match the criteria.

9.6.3 Triangles

The page **Triangles** is used for the filtering of triangles of a TIN (triangulated irregular network).

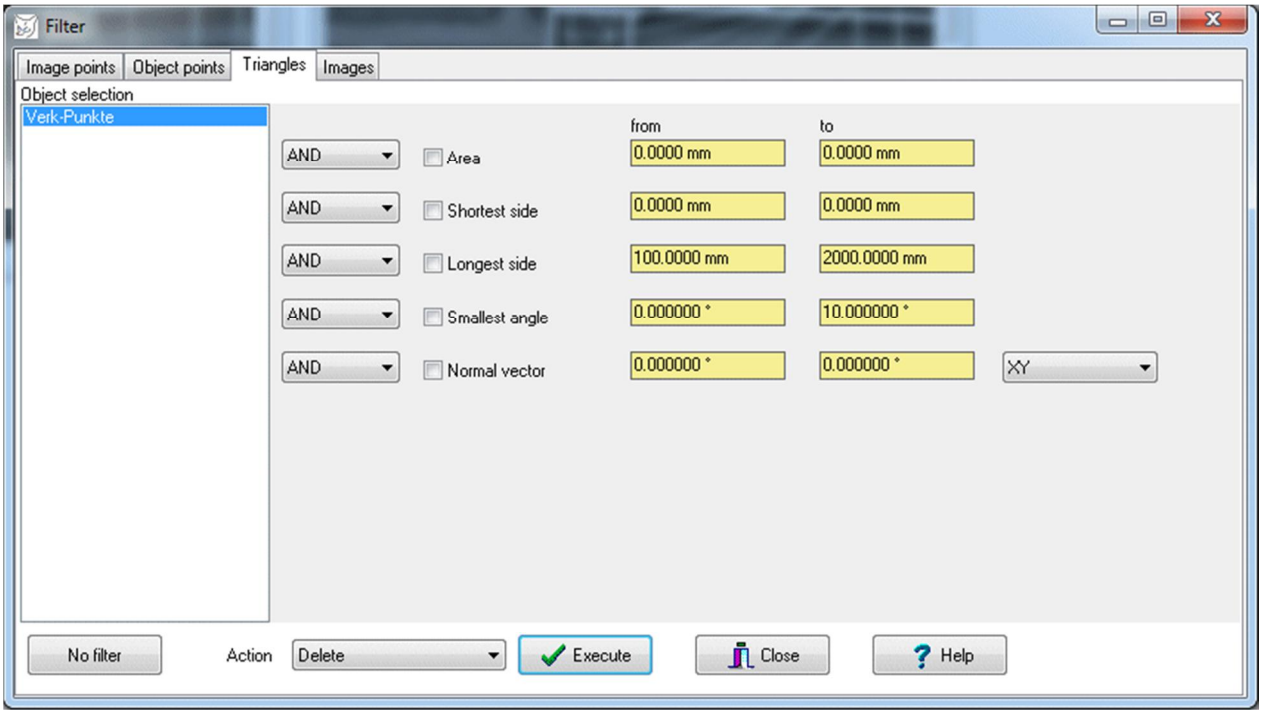


Fig. 103: Criteria for filtering of triangles

Under Object selection the objects are selected whose triangles shall be filtered.

The value intervals and logical conditions are set in the right side of the window. The following filter criteria are implemented:

Area	Selection of triangles with a specific area

Shortest side	Selection of triangles, whose shortest side complies with the conditions
Longest side	Selection of triangles, whose longest side complies with the conditions
Smallest angle	Selection of triangles, whose smallest inner angle complies with the conditions
Normal vector	Selection of triangles, whose direction of the normal vector is within a certain range of angles with respect to the selected reference plane

In the example above, all triangles are deleted if their longest side ranges from 100 to 2000 mm and the smallest inner angle lies between 0° and 10°. Filte ring of triangles is available only with the action *Delete*.

9.6.4 Images

The page **Images** is used for the filtering of images.

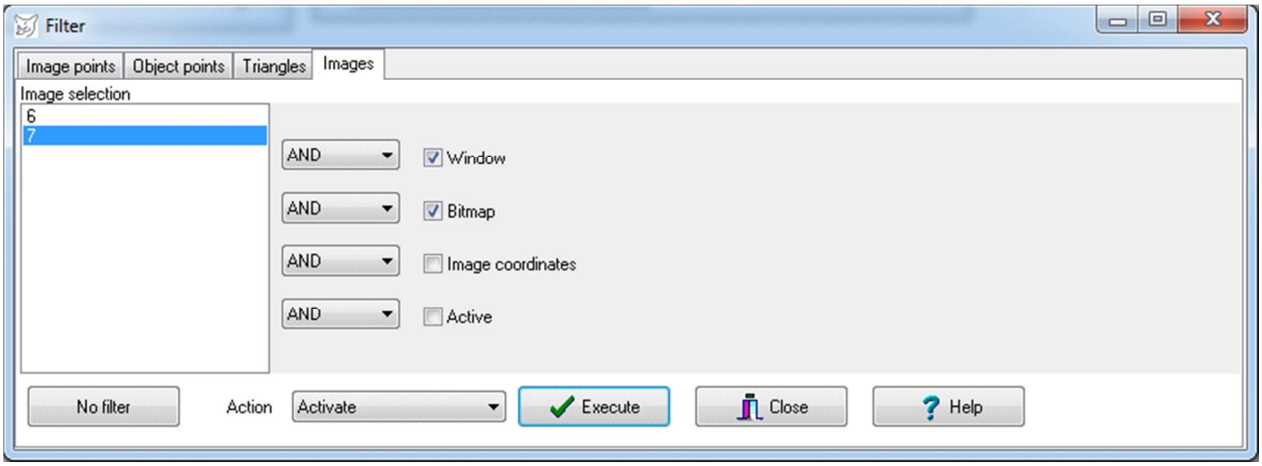


Fig. 104: Criteria for filtering of images

Under Image selection the images are selected which shall be filtered.

The items and logical conditions are set in the right side of the window. In the above example, all images are activated if they consist of an open image window and if a bitmap is loaded. Only the actions *Activate*, *Deactivate* and *Delete* are available for the filtering of images.

9.7 3D transformation

Menu:	Objects → 3D transformation
Precondition:	Two objects with existing points

The function **3D transformation** is used for the spatial similarity transformation of two 3D objects. A 6- or 7-parameter transformation is calculated between two 3D point lists. There are also 2D transformations available for test purposes.

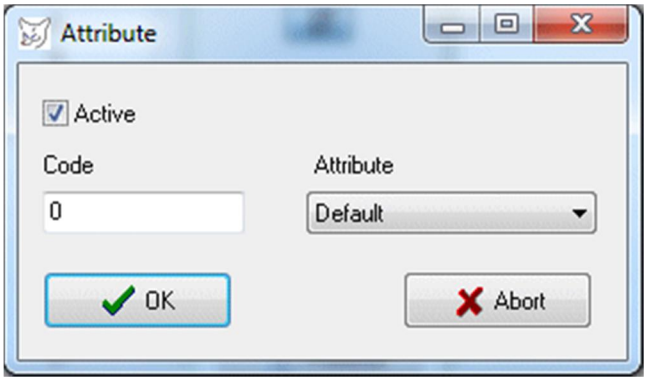
Under Source object (xyz) is the object selected and displayed, from which the points are transformed into the target system. The button [...] opens the dialog **Objects/Object properties** to the selected object. The same applies for the Target object (XYZ). The points selected in the two lists with identical point number are used to calculate the 3D transformation. A popup menu provides the following functions:

Select all Selects all points

Toggle selection Inverts the selection

Select points Opens a dialog for the individual selection of points (see **Objects/Object properties/Object coordinates**)

Attributes Opens a dialog for the definition of point attributes (Code):



Active Activate or deactivate the points

Code Point code

Attribute Selection of predefined codes which define the meaning of a point for particular transformations (see below)

Under *Transformation* various transformation functions are available:

3D Helmert 7 Par Full 3D transformation with scale factor

3D Helmert 6 Par Full 3D transformation without scale factor

3D Eigenvalues Full 3D transformation with scale factor based on eigenvalue analysis

3D 3-2-1 3D transformation by means of 3-2-1 method (not yet implemented)

3D uvw 3D transformation into a local system of three points. To do this, three points must be marked with the attributes Point1 (code 8), Point2 (code 9) and Point3 (code 10). The origin of the resulting uvw coordinate system is located within Point1, the v-axis goes through Point2. A target object is not required.

3D 6DOF Full 3D transformation with scale factor, where in both systems exactly three points have to be selected which may not lie on a common straight line. The function is equal to the method of calculation of approximate values for the general 3D transformation.

2D Affine 6 Par Plane affine transformation with the X- and Y-coordinates of the object

2D Helmert 4 Par Plane Helmert transformation with X- and Y-coordinates of the object

2D Projective 8 Par Plane projective transformation with X- and Y-coordinates of the object

2D Polynomial Plane polynomial transformation with the X- and Y-coordinates of the object and the polynomial degree as defined under **Edit/Options/Compilation/Rectification**

With Calculate the calculation is performed, under Output log an output logfile of calculation can be displayed. The level of detail of the output log can be set under **Edit/Options/Compilation/3D calculations**.

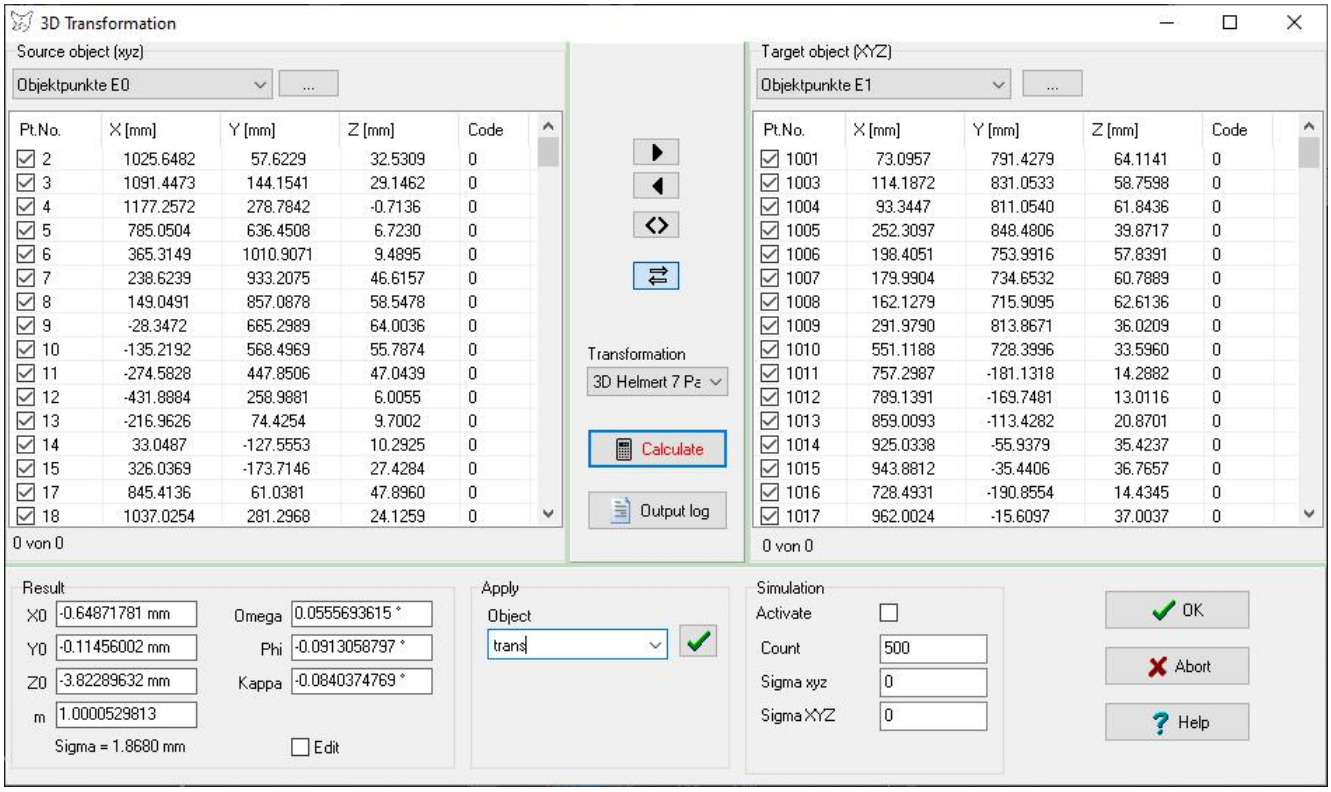


Fig. 105: 3D transformation

Under Result the computed transformation parameters are displayed. The angle of rotation may be ambiguous because they are derived from the computed rotation matrix using quaternions. *Sigma* denotes the root mean square deviation of the transformed source points to the points of the target. Activating *Edit* allows to edit the values.

Under Apply the displayed (and optionally edited) transformation parameters can be applied to the selected *Object*. By choosing an existing or by entering a new object name and pressing the button ✓, the points of the source object are transformed into new 3D coordinates saved to the *object*. The user is asked whether the currently selected or all source point shall be transformed. In addition to the transformed coordinates each point of the object contains the values sigmaX, sigmaY, sigmaZ as differences of the transformed point coordinates to the coordinates of the target.

Under Simulation additional noise Sigma xyz or XYZ Sigma can be assigned to the coordinates of the two objects in the context of a Monte-Carlo simulation. For the simulation a number of iterations as entered under *Count* will be calculated where in each iteration a normally distributed random noise will be added and the 3D transformation will be computed. With Calculate the simulation is started if it has been switched on with *Activate*. The transformation parameters calculated in each iteration are stored in the file SimuTrans.txt and can then be analyzed from there.

The window is closed with OK if the determined parameters shall be stored to the source object. They can be displayed and applied under **Objects/Object properties/Transformation**. With Cancel the window is closed without saving the data.

9.8 Meshing

Menu:	Objects → Meshing
Precondition:	Loaded project and existing object

The function **Meshing** is used for calculating a Delauney triangulation (meshing) of 3D points of a selected object. Currently, the function is restricted to the XY-plane of the points. *Object points* or *point clouds* can be used. If the meshing of point clouds shall be performed, the option *Object points* may not be selected.

After calculation a list of triangle points is created to the current object. The graphical display of the triangles in the image can be managed under **Edit/Options/General/Graphics**.

The management of stored triangles is done under **Objects/Object properties/Triangles**.

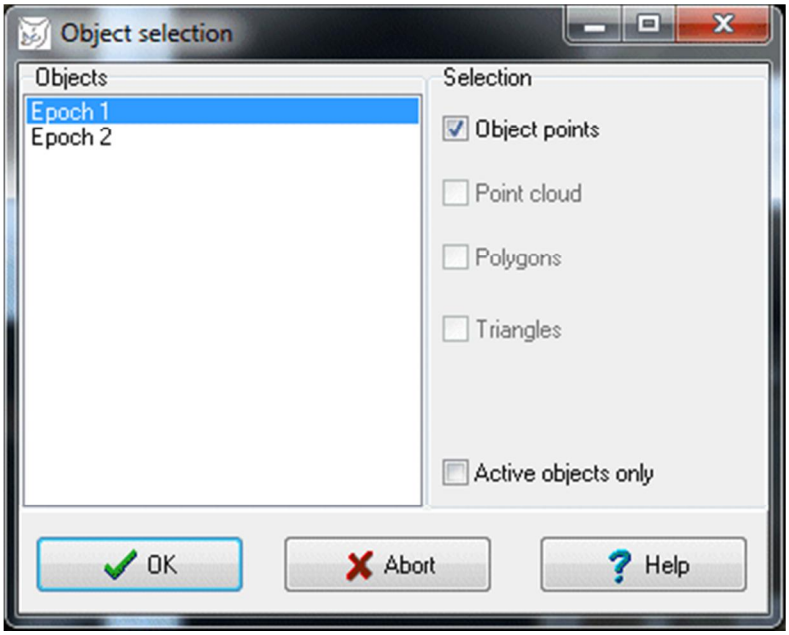


Fig. 106: Object selection for meshing

9.9 Deformations

Menu:	Objects → Deformations
Precondition:	Loaded project and existing object

The function **Deformations** is used for calculating deformations between two 3D objects.

Under Objects the two objects are selected. The button Synchronize is used to adapt the point numbers of both objects. The point number of a point in object 1 is assigned to that point of object 2 that has the shortest distance to point 1. Therefore, all points of both objects get the same number which are closest to each other. The point list of object 2 will be modified and cannot be restored after.

Under Calculation the method for analyzing deformation is selected. The following methods are available:

Differences: The coordinate differences between all identical points (same point number in each object) are calculated as object 2 - object 1.

The table displays *Average*, *RMS* value and *maximum* deformation for any coordinate direction and their *mean* value. With  , a calculation log file can be displayed that is stored in file deformation.txt.

Under Output the computed deformations can be stored. With Save the computed deformations are added as standard deviations to all points of the selected object, i.e. the original coordinates remain unchanged. In the drop-down list an existing object can be selected or the name of a new object can be entered. With Export it is possible to save the point coordinates of object 1 and the computed deformations as a text file.

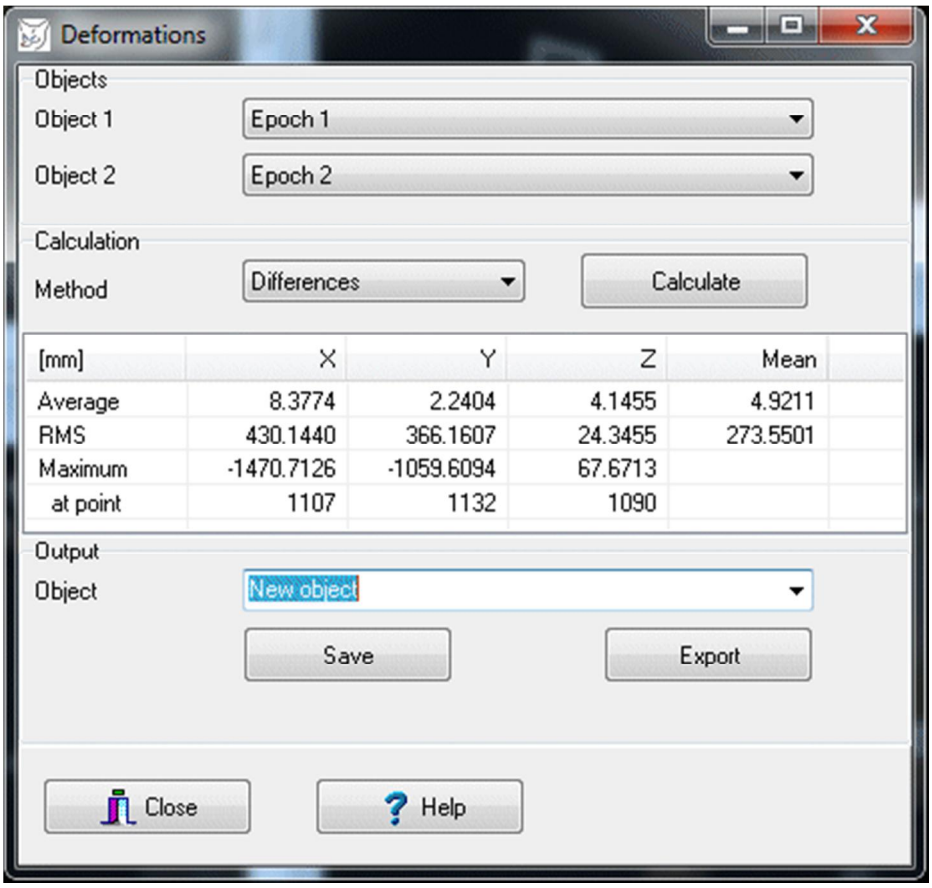


Fig. 107: Deformations

9.10 Image to object

Menu:	Objects → Image to object
Precondition:	Existing image object

With the function **Image to object** the image coordinates of the selected image are converted into 3D object coordinates and stored at the selected object.

Image Selection of the image

Correction Correction of image coordinates with the parameters of the interior orientation:
no distortion correction: using raw (measured) image coordinates
with distortion correction: the image coordinates are corrected by principal point shift and distortion prior to conversion into 3D coordinates.

Transformation The image coordinates are converted as follows:
no transformation: the 3D object coordinates consist of the image coordinates x', y', as well as the negative principal distance
with exterior orientation: the 3D image coordinates (x', y, c) are transformed with the parameters of the exterior orientation into object space.

	with projective transformation: the 2D image coordinates (x', y') are transformed with the parameters of the projective transformation assigned to the image .
Overwrite points	Existing object coordinates of the target object are overwritten with same number.
Object	Selection of the object: here an arbitrary name of the object to be created or an existing object can be entered

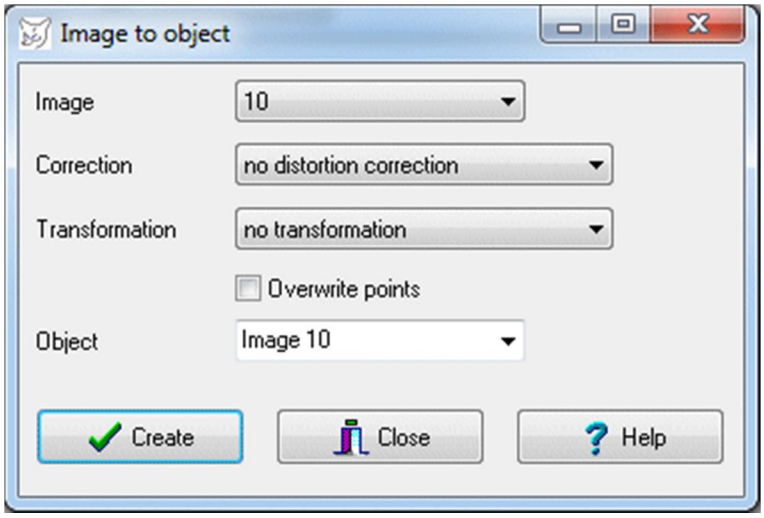


Fig. 108: Image to object

With Create all existing image coordinates are converted into object coordinates and saved. Subsequently, the process can be repeated by selection of another image. With Close the window is closed.

9.11 Color point cloud

Menu:	Objects→ Color point cloud
Precondition:	Existing image object with bitmap and object with point cloud

The function **Color point cloud** is used for the coloring of a point cloud with the color values of a selected image. Under Objects an object with stored point cloud is selected, and under Images one or more images that cover the object area of the point cloud are defined. The images must have parameters of interior and exterior orientation.

With Preview a preview of the colored points in the XY-plane is shown while no original data is changed. The background color of the preview can be set under **Edit/Options/General/Graphics**.

With OK the calculation is started. Every point of the point cloud is reprojected into all selected images. The color value of the pixel, which is closest to the center of the image, is assigned to 3D point. The RGB values saved to the point cloud can be listed under **Objects/Object properties/Point cloud** where they also can be exported to visualize them in another program.

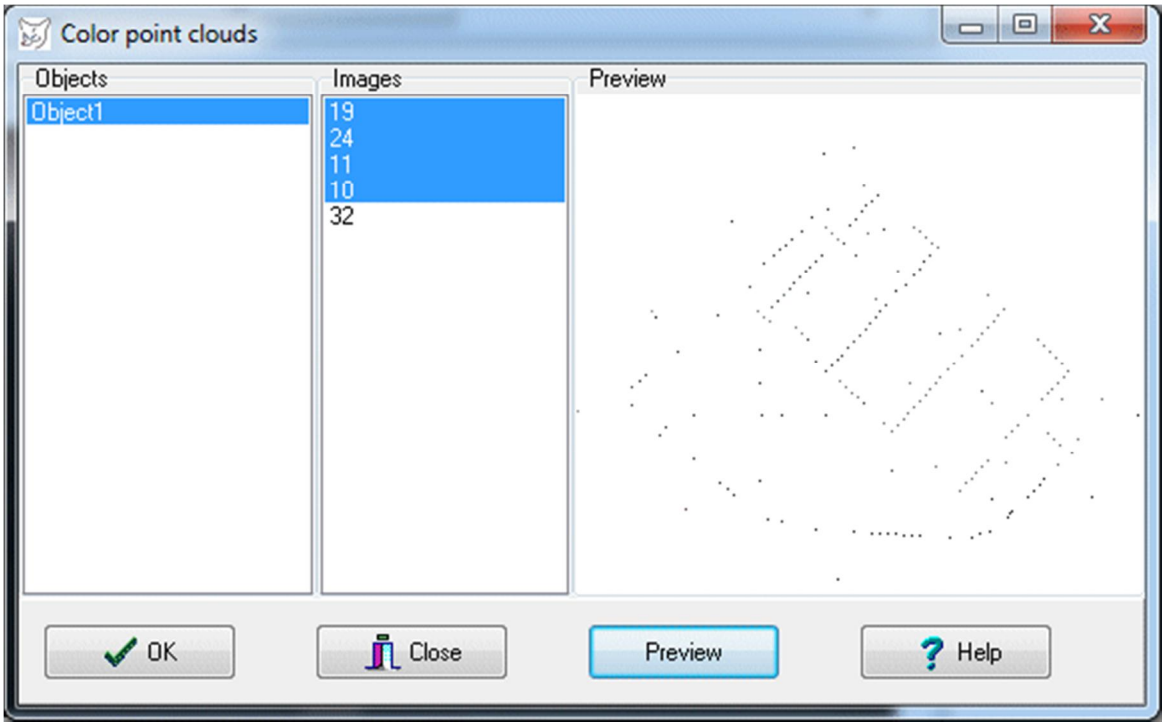


Fig. 109: Coloring of point clouds

9.12 Create point images

Menu:	Objects→ Create point images
Precondition:	Existing image object with bitmap and/or object with points

With the function **Create point images** image patches around image or object points are generated. The desired points and images are specified via a selection list. Each image patch is square by the dimension of *Window size*, which can also be defined under **Edit/Options/Cursor** with *Catch radius/Point images*. The image patches are extracted from all selected images that have allocated bitmaps. The display and management of point images happens in the expanded panel of the Point selection.

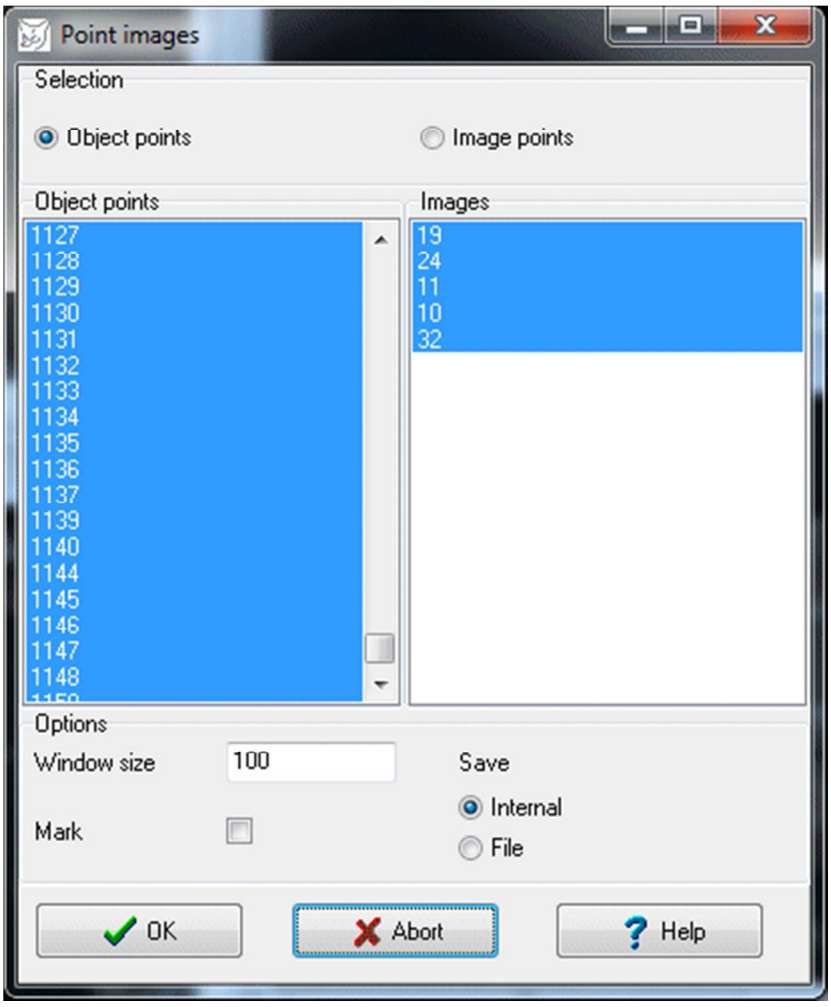


Fig. 110: Creating point images

With option *Object points*, image coordinates are computed from the selected 3D points for all selected images. If the option *Image points* is active, stored image coordinates of the images are directly used. If the *Mark* option is enabled, graphical symbols are drawn at the positions of the points. Graphical options for image and object point symbols are defined under **Edit/Options/General/Graphics**. At the image positions, image patches are extracted and stored.

If the option *Internal* is activated, the point images are stored only during program run. With option *File* the point images are stored in the subdirectory \PointImages\ as JPEG images. Each image patch thereby receives an individual file name composed by object name, point name, and a continuous index number.

10 Menu Graphics

The menu **Graphics** provides various graphical outputs.

10.1 3D viewer

Menu:	Graphics → 3D viewer
Button:	
Precondition:	Loaded project

The function **3D viewer** is used for visualization of 3D objects. The window remains permanently open, i.e. it can be worked with other program functions parallel to this representation. If input data has been modified, an update of the graphic is carried out with the function *Update* (see below) or by clicking on the graphic.

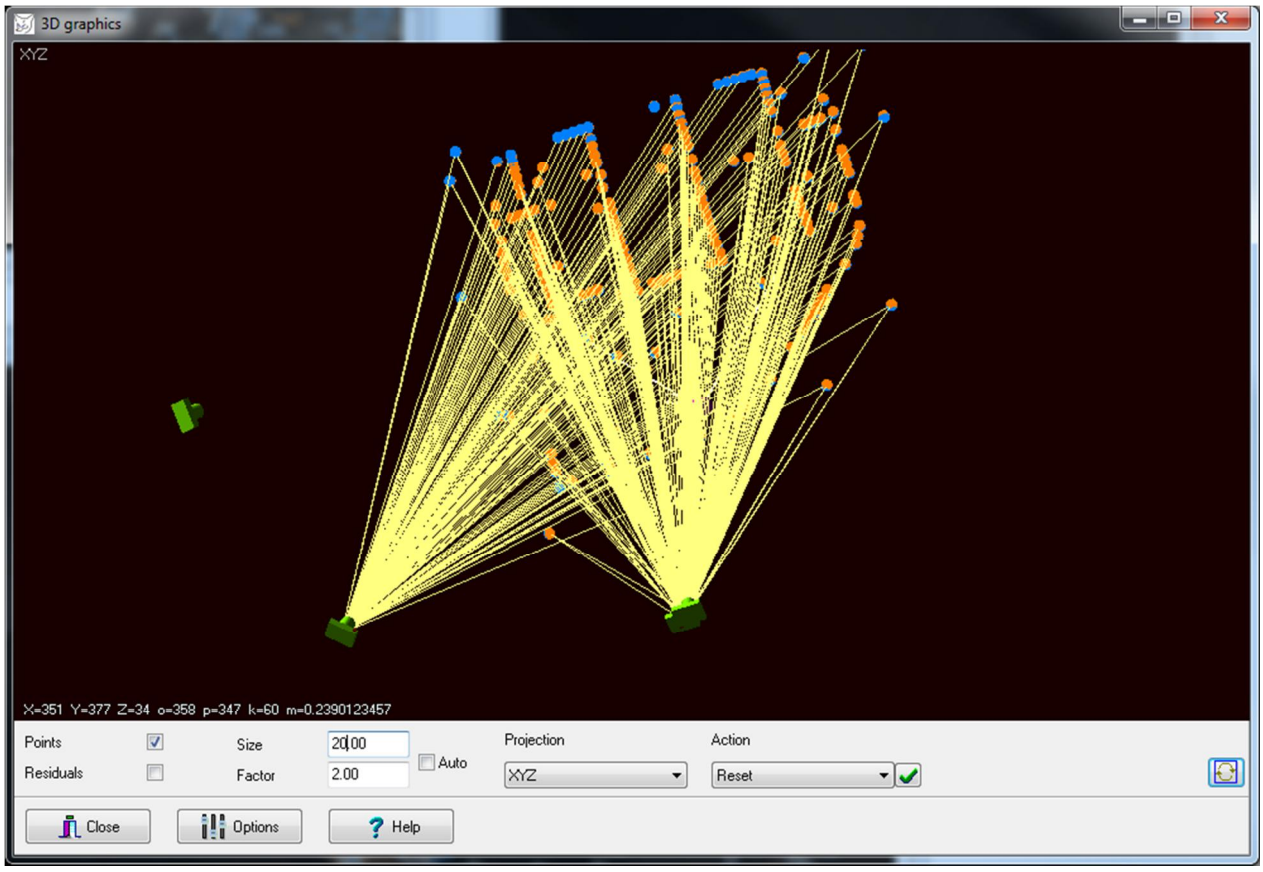


Fig. 111: 3D viewer

This viewer displays object points, camera positions, image rays and more three-dimensionally in a XYZ view or two-dimensionally in the projection planes XY, XZ or YZ. The items to be drawn are selected with the button Options or under **Edit/Options/Visualization**. The selection of projection is made via the upper drop-down list.

The graphic is operated using the mouse:

Left button:	Rotation about the X and Y axis in the XYZ view
Ctrl + mouse wheel:	Zooming of the view
Left mouse button + Ctrl	Zooming of the view
Left mouse button + Shift	Pan and scroll in XY direction
Left mouse button + Alt	Rotation around the Z axis in the XYZ view

The popup menu provides the following functions:

Reset	Resets the graphics to the default values
Fit	Resize the view so that the entire object is visible
Origin	Represents the origin of the coordinate system at the center of the graphic
Center	Displays the view at the center of the object
Coordinates	Sets values for position, angle and scale of the view
Bookmark	Stores the current viewing settings
Recall	Restores the stored viewing settings
Update	The graphic is redrawn
Copy	Copies the displayed range as a bitmap to the Windows clipboard

The lower drop-down list provides a short-cut to the functions of the popup menu. The button  executes the current function directly.

The following options are also adjustable:

Points	Display the object points
Size	Size of the displayed object points in mm
Residuals	Display of residuals of the object points as defined under **Edit/Options/General/Display**. If this option is selected, the field with the color scale will appear.
Auto	Displays the object points always in the same size, independently of the zoom
Factor	Amplification factor of the residuals
Min/Max	Calculates min/max values of object space. Minimum and maximum limits of the residuals associated with the color scale can be entered into the fields below.

10.2 VRML viewer

Menu:	Graphics → VRML viewer
Precondition:	Loaded project

With the function **VRML viewer** the currently installed VRML viewer is started as external program. If no VRML viewer is found or the VRML file is not displayed, a corresponding program can be defined in **Edit/Options/General/Program**.

Before display a temporary VRML file will be created in the current project directory ($$phox$ $.wrl) which contains the VRML data according to the menu function **Project/Export/VRML** and the settings under **Edit/Options/Visualization**. Each call to this function creates a new instance of the VRML viewer.

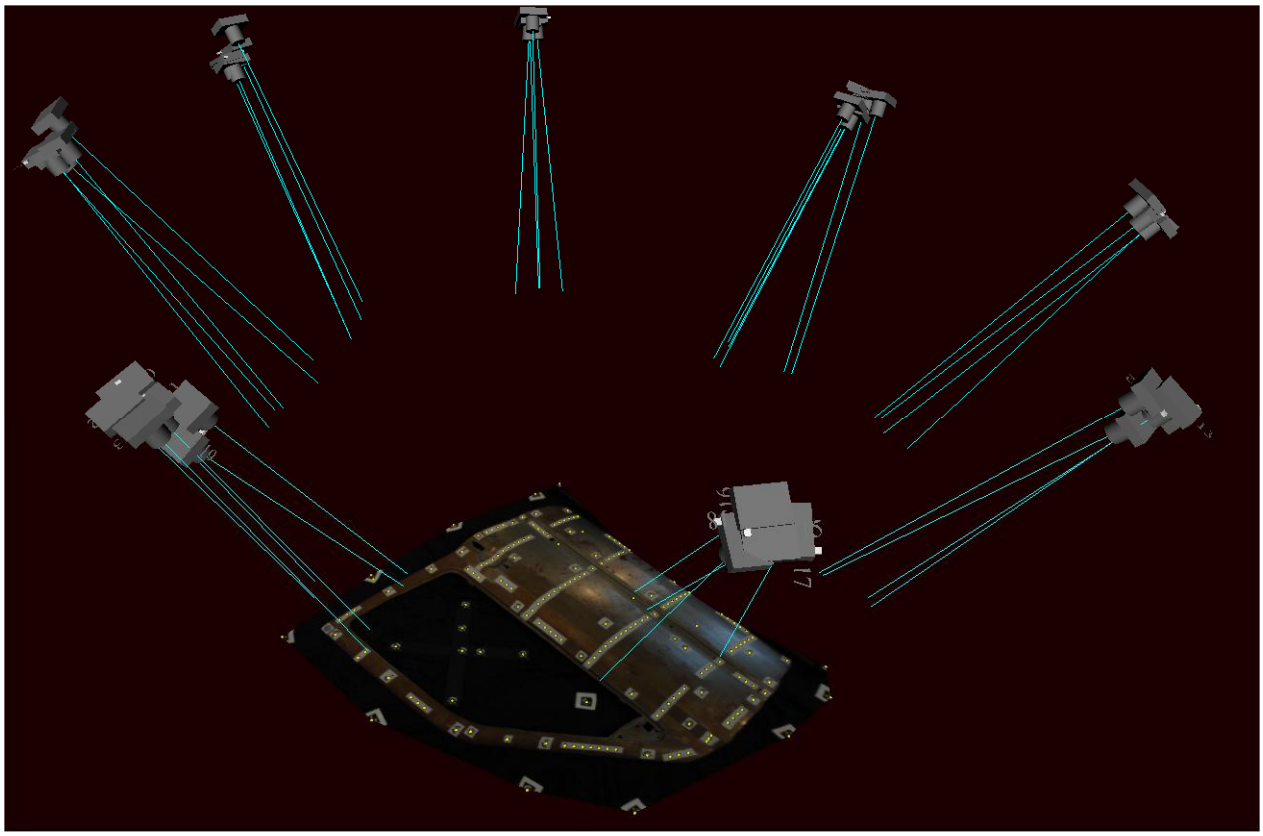


Fig. 112: VRML viewer with 3D visualization

10.3 Image footprints

Menu:	Graphics → Image footprints
Precondition:	Existing image object

The function **Image footprints** represents the outline of the object areas covered by the images.

Under Selection the images to be displayed are selected. Three options are available:

Images	Selection of individual images
Stereo model relative	Displaying two images of the selected stereo model in the model coordinate system, i.e. the parameters of the relative orientation; under Dimensions values in the range of the model coordinate system should be entered, i.e. the distance between the images is typically 1.
Stereo model absolute	Displaying two images of the selected stereo model in the coordinate system of the object, i.e. the exterior orientation parameters are applied.

Under Options the graphical output is determined:

Footprints	Represents the object area covered by the image (footprints)
Camera positions	Displays the positions of the perspective centers of the selected images
Optical axis	Displays the optical axis and their intersection points with the reference plane as well as the field of view of the selected images
Imaging path	Draws a line of consecutive image paths, for example, the path of an aerial flight
Grid	Displays a grid in the defined grid width
Object points	Displays the object points (green: selected points; red: all other points); optionally residuals of the object points can be plotted (see **Edit/Options/General/Display**) scaled by the setting of the slider
Image points	Displays image points projected into the reference plane

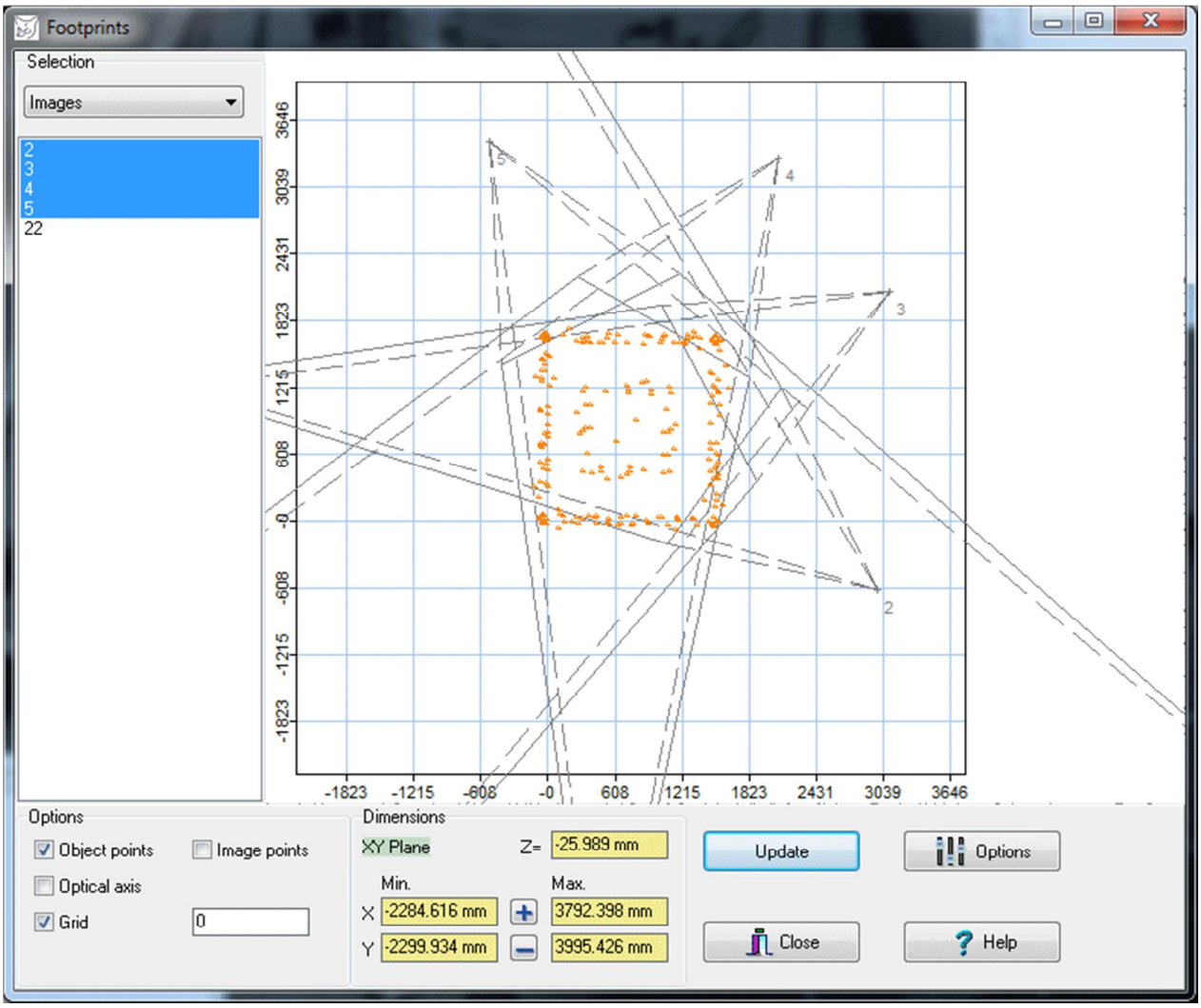


Fig. 113: Image footprints

Under Dimensions the rectangular object area is defined by input of corner coordinates X and Y (*Min/Max*). The distance to the reference plane is selected under *Z*. By clicking on the XY-plane field, the desired reference coordinate plane can be selected.

Each image is represented by its four corners projected into object space. For this purpose, the image format must be specified correctly in the camera data of the image. The coordinates of the recording locations (projection centers) are drawn with a + and the associated image number.

10.4 Distortion curves

Menu:	Graphics → Distortion curves
Precondition:	Existing image object

The function **Distortion curves** graphically represents the distortion effects of the image due to the stored distortion parameters. In the center panel, charts for distortion curves and plane representations appear.

The represented parameters are selected in the upper panel:

Image:	Selection of the image based on the image number. By default, the distortion of the selected image is displayed. If one or more images are checked, multiple curves in the diagrams appear according to their individual parameters.
Camera:	If a camera is associated with the selected image, the camera name appears
Info	Display of the window with Image properties
Effect:	Represents the effect of the distortion in the image, i.e. the diagrams indicate how the image is distorted.
Correction:	Represents the diagrams as if a correction of the distortion would be applied.
Rad.sym. distortion:	Representation of the impact of the radial symmetric distortion (parameters A_1 to A_3)
Decentring distortion:	Representation of the effect of tangential and asymmetric distortion (decentring distortion, parameters B_1, B_2)
Affinity and shear:	Representation of the impact of affinity and shear (parameters C_1, C_2)
Distortion map:	Representation of the impact of a loaded distortion table (lens map function)
All:	All distortion effects

The upper left diagram represents the radial distortion curve as usual in photogrammetry where the impact $\Delta r'$ depending on the image radius r' will be displayed. At r_0 the curve has an optional second zero-crossing (r_0 can be null). The range of values of the y-axis is *automatically* determined or set be entered *min.* and *max*. *distortion* values. The maximum representable image radius is adjusted by the entered value of *max. radius* or calculated *automatically*. The output units for the chart axes can be selected by *Unit dr* and *Unit r*. If a camera is associated with known physical pixel sizes, here also the output unit pixels can be selected. By double-clicking the graphic more Diagram properties can be set. The *Color* field defines the line color of the distortion curve or the distortion vectors.

The bottom left diagram represents the distortion curve as used in photography, where the percentage impact $\Delta r'/r$ depending on the image radius r' will be displayed. The curve has also a second zero-crossing at r_0, whereby r_0 is uncommon in photography. By double-clicking the diagram more Diagram properties can be set.

The right graph represents the effect of distortion in the image format. Different output options are available:

Points:	Displays a regular image point grid with given *point distance*.
Vectors:	For the points of the image point grid vectors are drawn representing the direction and length of the distortion effect. The length can be adjusted with the *vector scaling* factor.
Grid:	A distorted point grid with given *point distance* and the scale factor of *vector scaling* will be shown.
Base grid:	A undistorted point grid is displayed.
Radius r0:	Draws a circle with the radius of r_0.
Image:	If present, the bitmap of the represented image format is drawn.

Color scale: The distortion vectors and grid are dusplyed in coded colors for the entire image format. The corresponding color scale is displayed below the graph. With Options the color scale the color palette can be adjusted (see **Edit/Options/General/Display**). The minimum and maximum limits correspond to the values for minimum distortion and maximum distortion. With the *color scale factor*, the limits can be scaled so that a smaller or larger range of color scale is used. The effects in the image can be displayed more clearly for very little distortion values and a major factor of color scaling.

Color scale: The distortion values are represented in coded colors for the entire image format. Here the same conditions as described under *Color scale* are valid.

For the graphics the following functions are available by the corresponding popup menu:

Properties Opens a dialog for setting Diagram properties (only for line diagrams)

Copy Copies the graphic as bitmap into the Windows clipboard

Export Exports the distortion data into a text file (Excel format)

Diagram window Transfers the distortion data into the Diagram window and displays it.

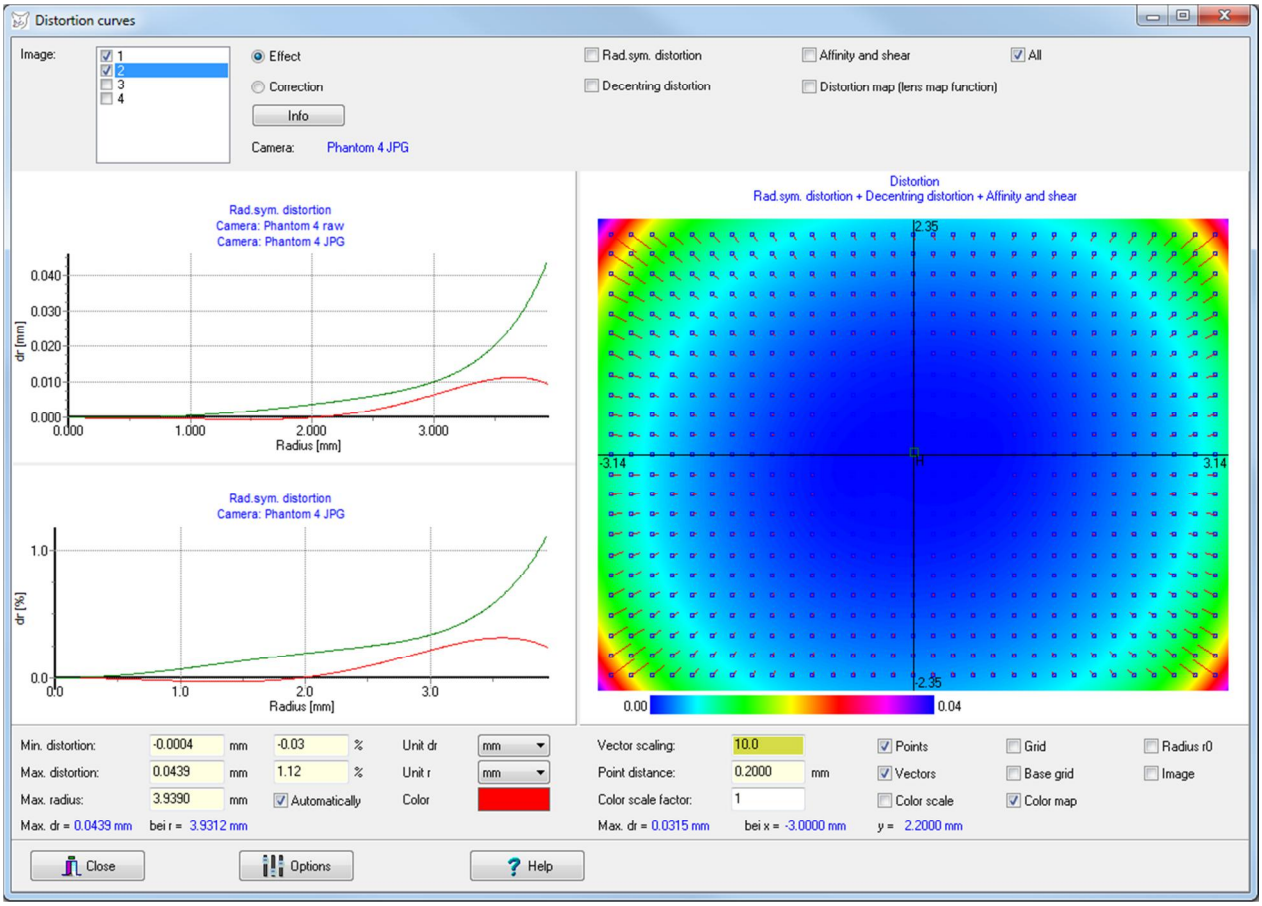


Fig. 114: Output of distortion curves

10.5 Analysis

Menu:	Graphics → Analysis
Precondition:	Loaded project

The function **Analysis** provides graphical analysis of data and measurement results.

The button Options calls the general program settings. The button Update redraws the graphic if necessary. The button Properties opens a window for Diagram properties.

The button Table opens the Diagram window with the currently drawn chart values. There the displayed values can be copied to the Windows clipboard, and thus for example directly into Excel.

In the displayed diagrams the following mouse functions are available:

Click on coordinate axis:	Calls the Diagram properties
Dragging with left button:	Zooms in the defined area (reset by dragging from right to left)
Dragging with right button:	Shifts the drawing area
Right mouse button:	Popup menu with the following functions: **Copy**: copies the diagram as a bitmap to the clipboard **Proportional**: represents approximately the same scale in X- and Y-axes **Properties**: calls the Diagram properties **Legend:** displays a legend to the diagram

Under Functions a list of analysis functions appears to which a graph and optional additional data is shown. In the lower left panel, various drawing options can be selected. Currently the following functions are implemented:

Image point distribution	Representation of image coordinates in image format
Image residuals vs. radius	Representation of image residuals as a function of the image radius (distance from the principal point)
Histogram of image residuals	Frequency distribution of the residuals of the image coordinates
Image statistics	Medium and maximum residuals of image coordinates
Camera positions	Representation of the exterior orientation with footprints
Orientation values	Values of interior and exterior orientation of an image sequence
Image to image	Vectors between the image points in two images
Image scales	Medium image scales of selected images
Object to image	Distribution of selected object points in the currently selected image
Object point distribution	Distribution of object points of selected objects
Object residuals vs. distance	Representation of object residuals as a function of the distance from a reference point
Histogram of object residuals	Frequency distribution of the residuals of the object coordinates
Object to object	Vectors between the points of multiple objects
Length measurement error	Indication of the length measuring deviations between corresponding lines of two objects

Relative orientation Values of the interior and relative orientation of selected stereo models

Under Selection the desired objects and images are selected. Under Coordinates the coordinate plane is selected, for which the 2D graphics will be shown.

Object points are drawn with the symbol properties as defined for each object under Object properties. The symbol properties can also be accessed via right click in the list of objects.

The page Layout collects general layout items that are equal for all drawings:

Legend Optional display of a legend with selected positions *left*, *right*, *top* or *bottom*.

Project Optional output of the project file name in the top left corner

Date Optional output of the current date and time in the bottom right corner

10.5.1 Diagram properties

To set diagram properties, a dialog is opened. With Test the diagram will be updated with the selected parameters. With Accept the settings are accepted and the diagram is updated. With Close the window closes, optionally without changes. All diagram settings are stored only temporarily and must be re-entered during the next program run if necessary.

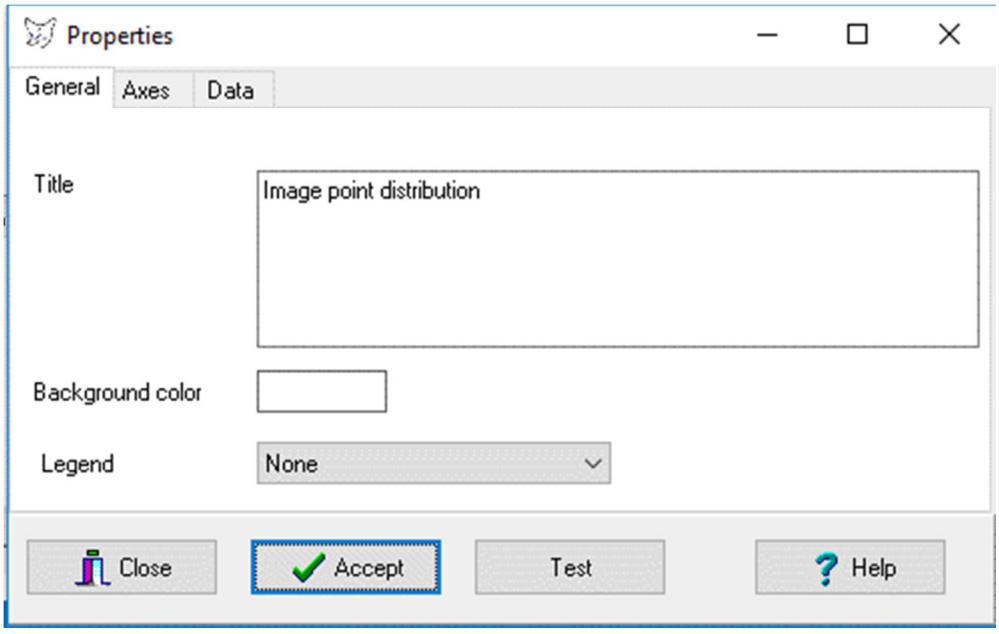


Fig. 115: General diagram properties

Under **General** settings for the display of the diagram are defined:

Title Text of the diagram title (optionally multiple lines)

Background color Color of the background of the diagrams

Legend Optional display of a legend to the diagram at position left, right, top or bottom.

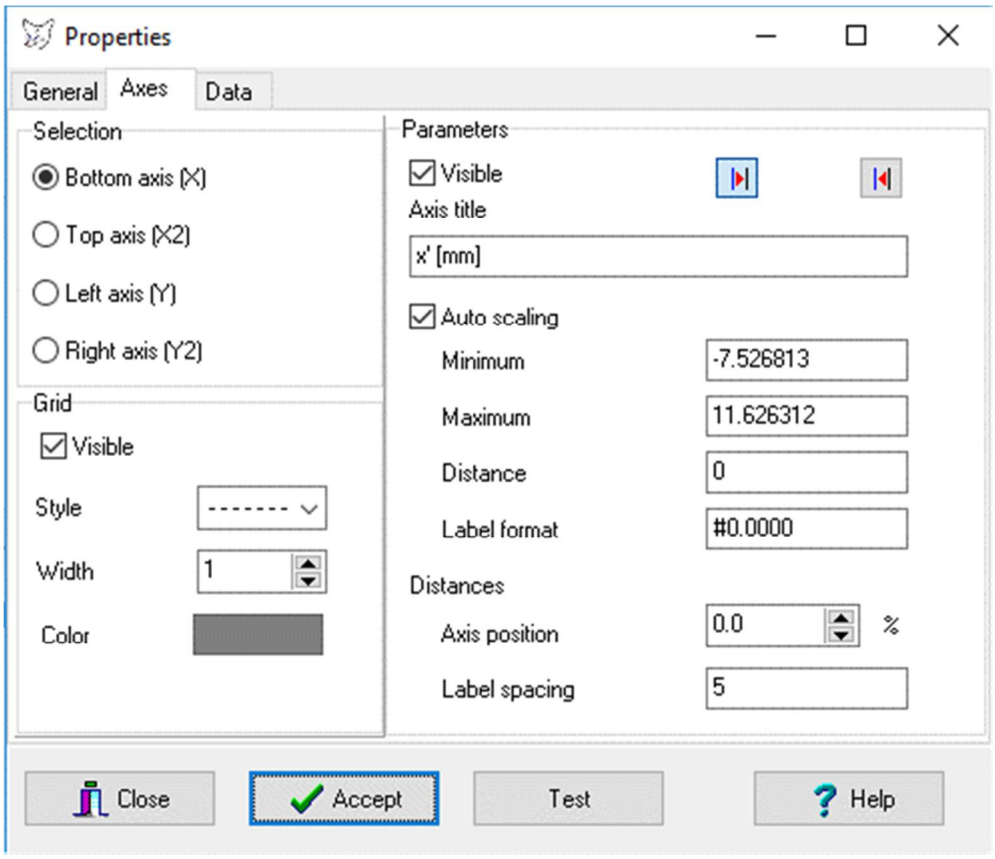


Fig. 116: Axis properties

Under **Axes** settings for the display of the coordinate axes are defined:

Selection Selection of one of the four axes of the diagram

Parameters Specific parameters of the selected axis::

Visible: Display the axis

Axis title: Label of the axis

Switches the automatic transfer of axis data to the parallel axis on or off

Accepts the parameters of each parallel axis, to represent both axes identically

Auto scaling: Minimum and maximum axis values are automatically determined

Minimum: Minimum value of the axis

Minimum: Minimum value of the axis

Distance: Distance between the displayed values

Label format: Format of floating point numbers as a string in the form "0.000" (example with three decimal places)

Distances:

Axis position Relative position on the counter axis in percentage. Example: X-axis = 50% draws the axis at 50%of the Y-axis

	Label spacing:	Distance for axis labels
Grid	Settings for grid lines	
	Visible	Display the grid lines
	Style	Line style
	Width	Line thickness
	Color	Color of the grid lines

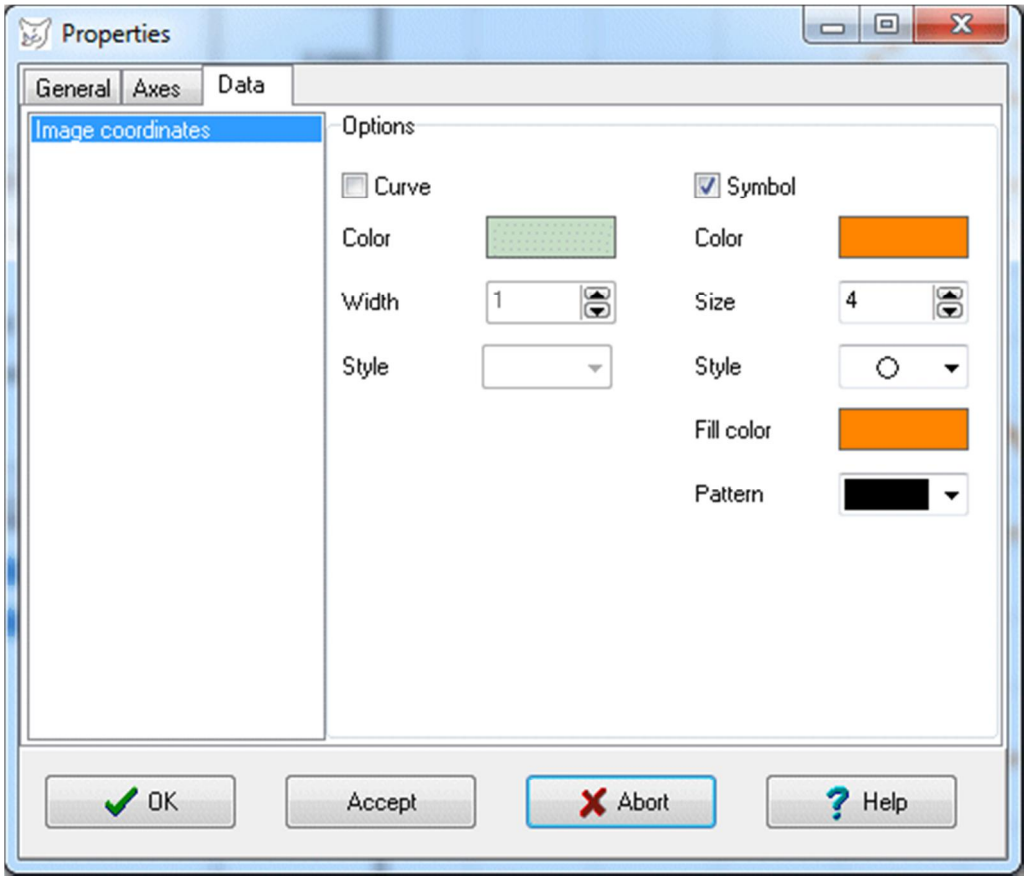


Fig. 117: Data properties

Under **Data** settings to display the selected data series are defined.

Curve	Display the data curve with the specified *Color* and *Width*. The following line styles can be selected under *Style*: 0: solid line 1: dashed long 2: dashed short 3: dot dash long 4: dot dot dash 5: No line
Symbol	Display of each data point in the specified *Color* and *Size*. Following symbols can be selected under *Style*: 0: filled rectangle 1: filled circle

2: filled triangle up

3: filled triangle down

4: horizontal cross

5: diagonal cross

6: horizontal and diagonal cross

7: filled diamond

8: no symbol

10.5.2 Image point distribution

The function **Image point distribution** represents the stored image coordinates of the selected images in a common diagram. The graphic allows to check whether there is a uniform or non-uniform (unfavorable) image point distribution.

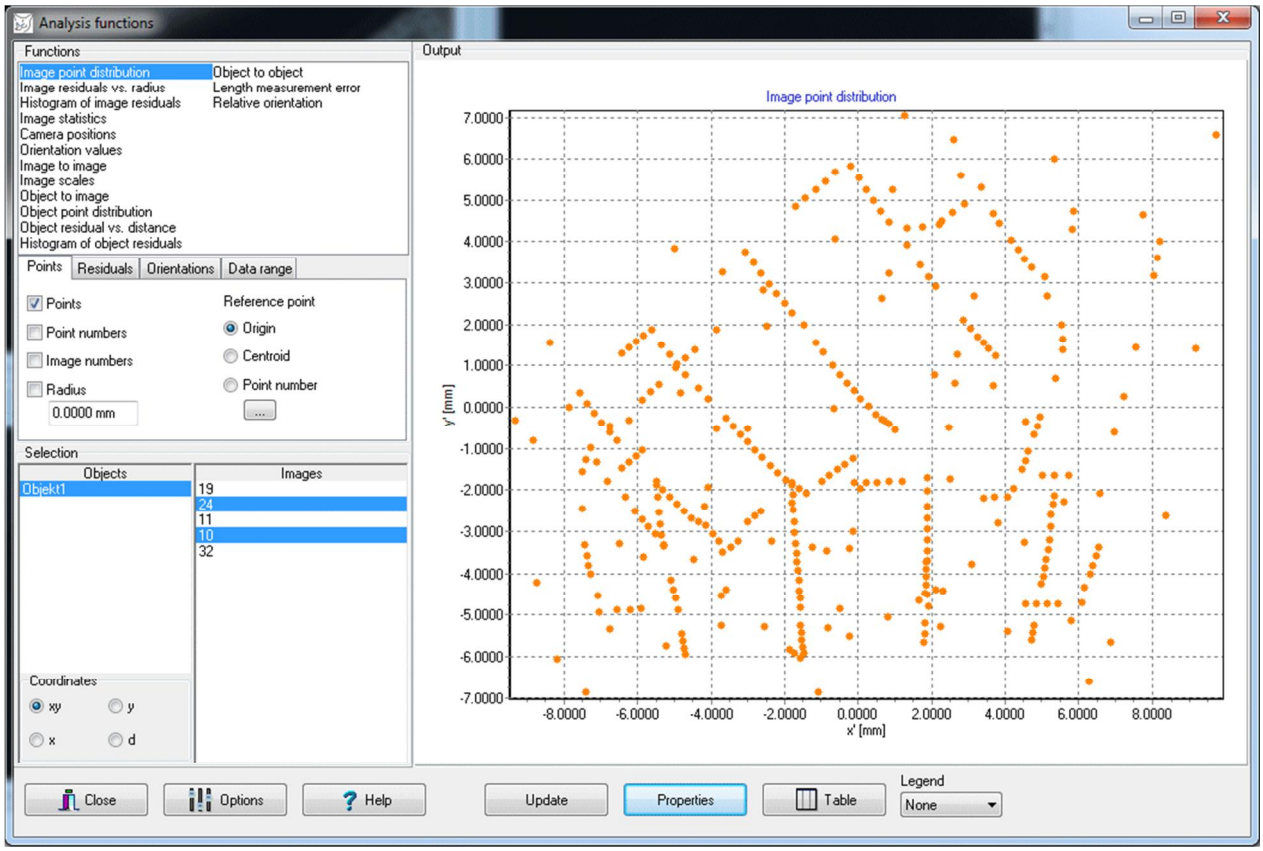


Fig. 118: Image point distribution

The following settings can be made under Points:

Points	Display of point symbols
Point numbers	Display the point number for each image point
Image numbers	Display the image number to every image point
Radius	Overlay of a circle with the given radius

The following settings can be made under Residuals:

[drop down list] Display of residual vectors, if stored to the image coordinates.

Vector length Enter of a value or use the slider to scale the length of the error vectors. A scale bar is displayed of the vector length entered under ↔.

The following settings can be made under Data range on page *Image coordinates*:

Apply The specified coordinate limits are used for the diagram (no auto scaling).

[...] Call of a window to enter of the coordinate values.

Using the sensor format associated with the selected image.

10.5.3 Image residuals vs. radius

The function **Image residuals vs. radius** represents the residuals (standard deviations) of image coordinates of the selected images in a common diagram. It allows to check whether a dependency exists between distance to the principal point (image radius) and the deviations.

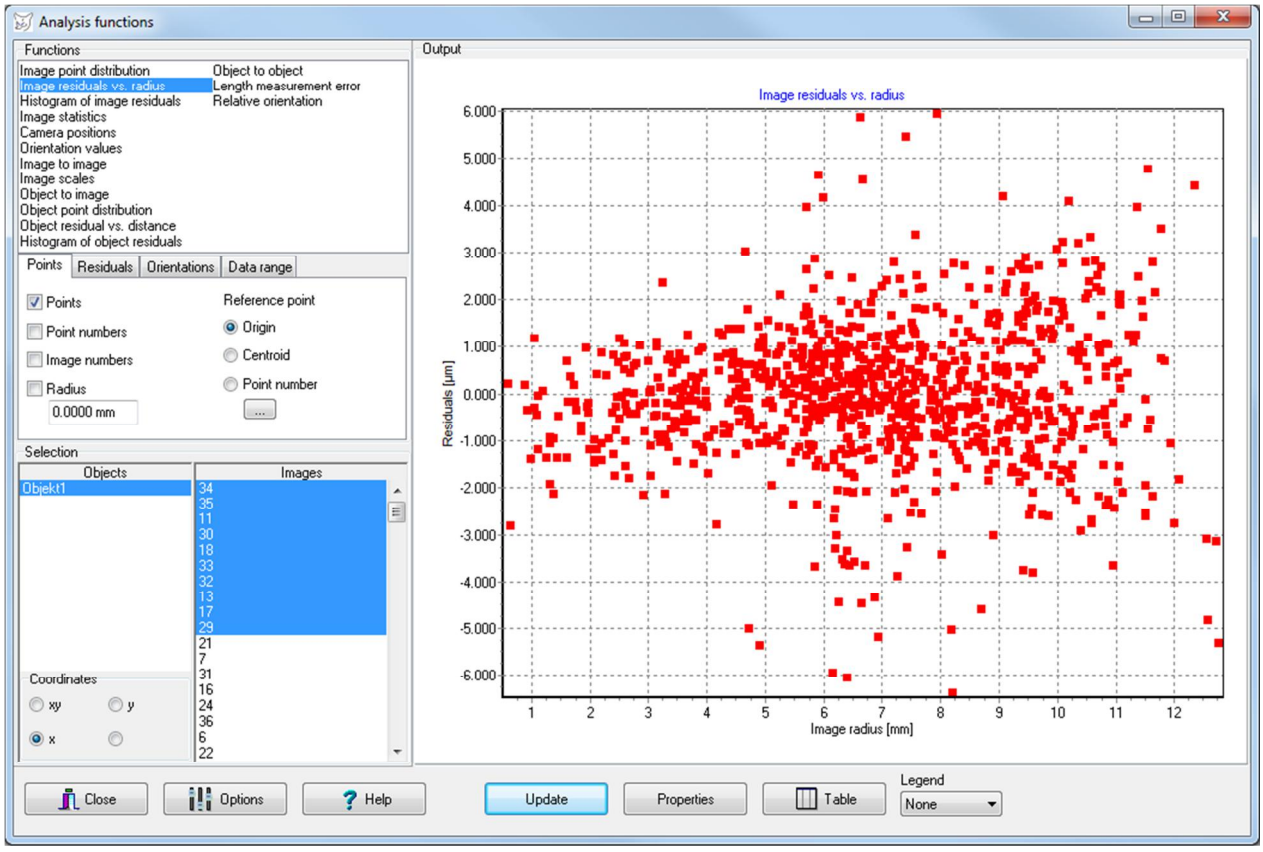


Fig. 119: Image residuals vs. image radius

The following settings can be made under Points:

Point numbers Display the point number for each image point

Image numbers Display the image number to every image point

The following settings can be made under Coordinates:

xy Residuals resulting from $v = \sqrt{sx^2 + sy^2}$

x Residuals resulting from $v = sx$

y Residuals resulting from $v = sy$

10.5.4 Histogram of image residuals

The function **Histogram of image residuals** represents the residuals stored to the image coordinates (standard deviations) of the selected images in a histogram. It allows to check whether the residuals are sufficient for a systematic distribution.

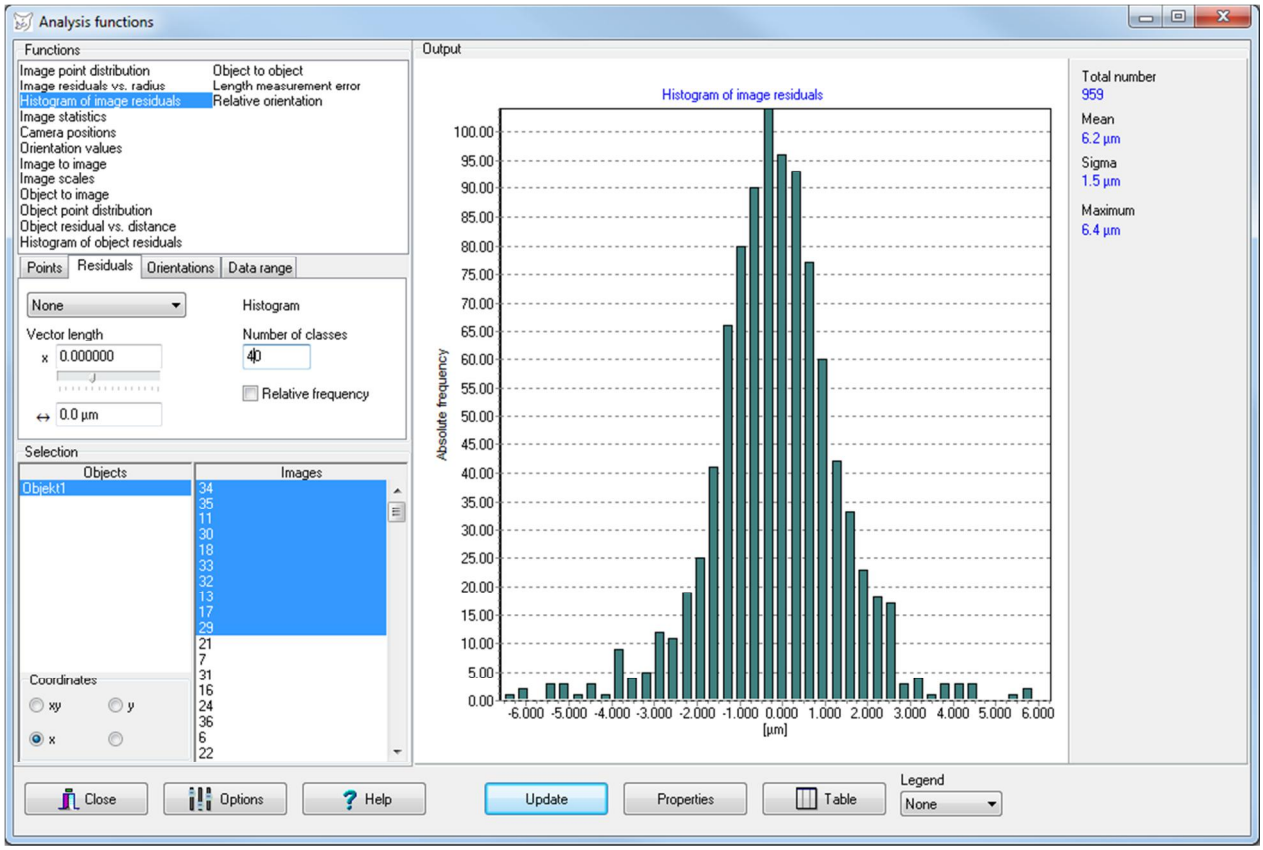


Fig. 120: Histogram of image residuals

The following settings can be made under Residuals:

Radius Analysis of only those points that lie within the defined radius

Number of classes Number of classes in which the residuals are classified

Relative frequency Specifying relative instead of absolute frequency

The following settings can be made under Coordinates:

xy Residuals resulting from $v = \sqrt{sx^2 + sy^2}$

x Residuals resulting from $v = sx$

y Residuals resulting from $v = sy$

10.5.5 Image statistics

The function **Image statistics** represents the mean and maximum residuals of the selected images as a function of image number.

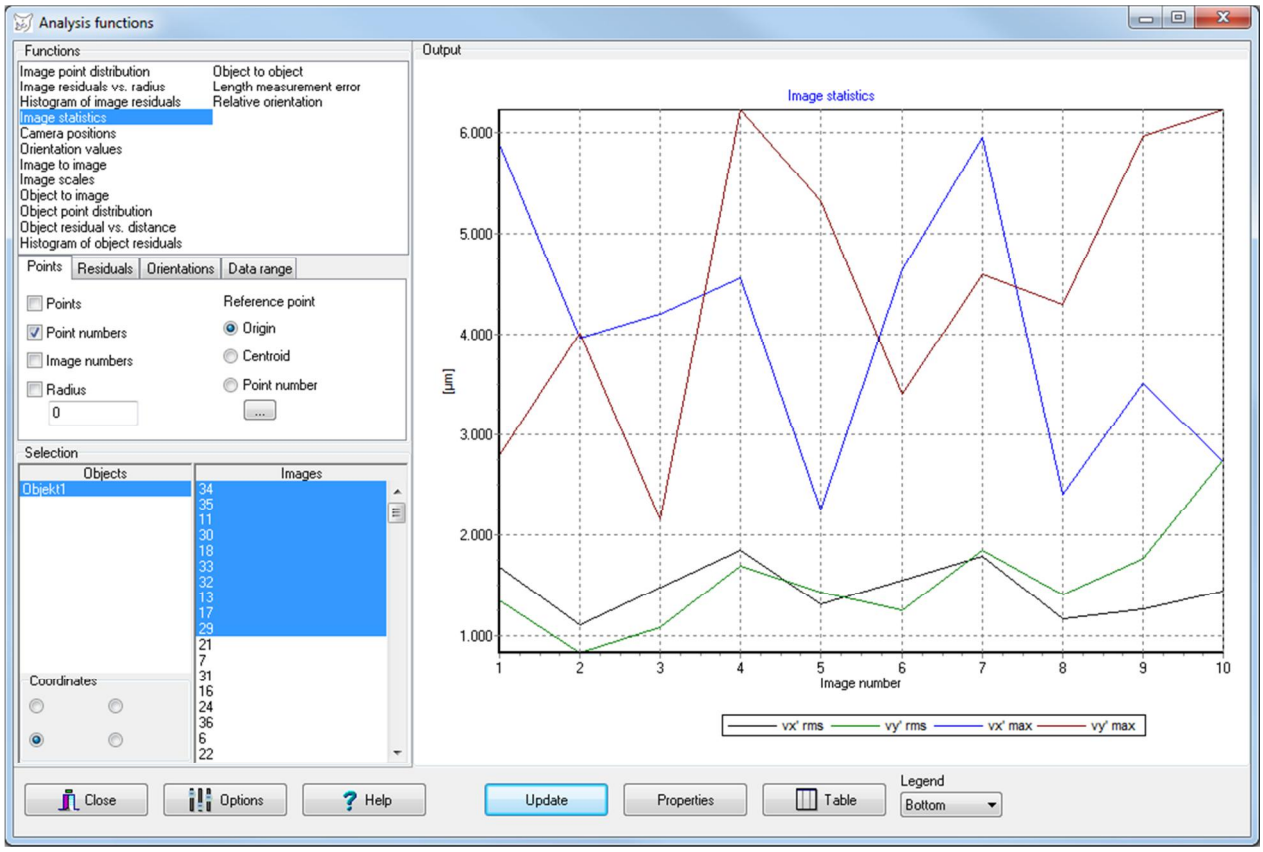


Fig. 121: Distribution of average and maximum image residuals

10.5.6 Camera positions

The function **Camera positions** displays the translation values of the exterior orientation and footprints of the selected images in coordinate plane selected under Coordinates.

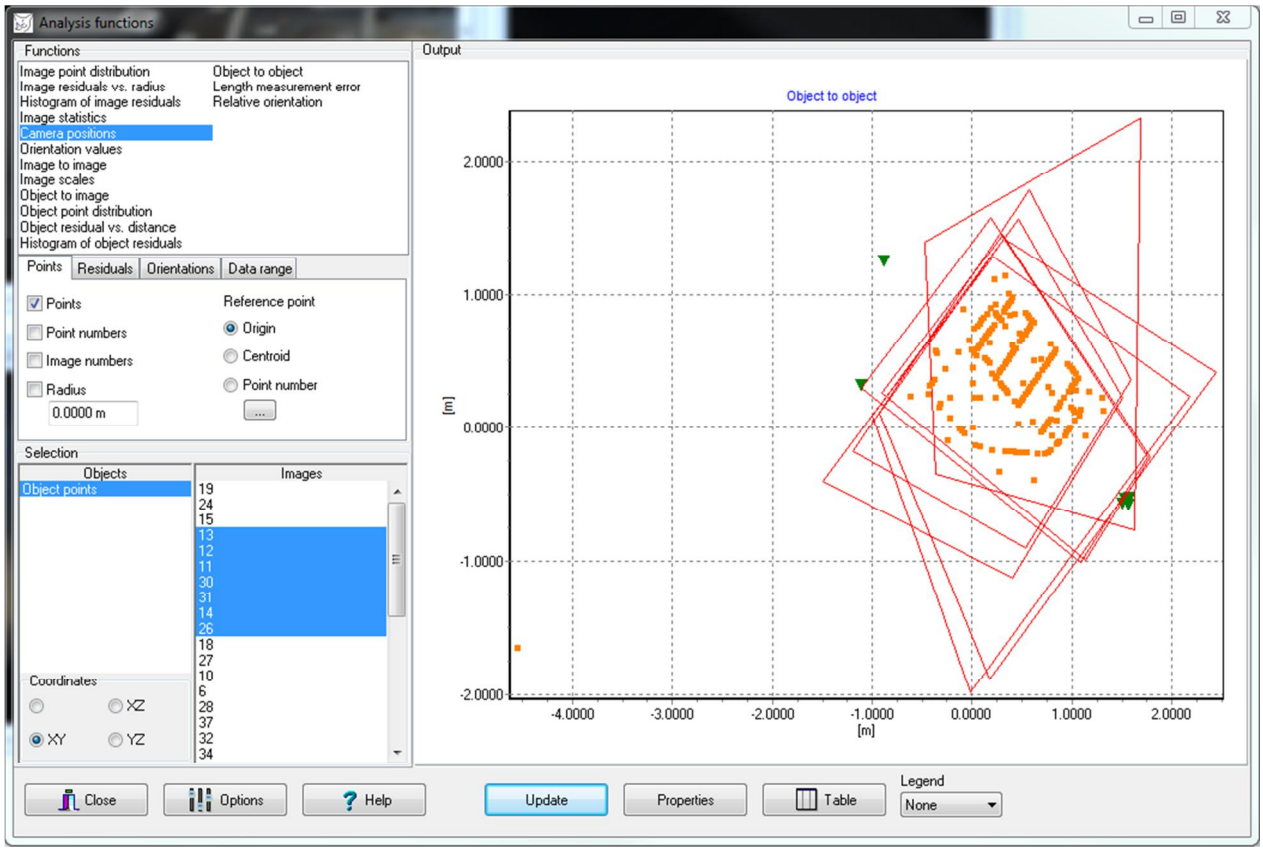


Fig. 122: Camera positions

The following settings can be made under Coordinates:

XY Display the XY coordinates of the projection centers.

XZ Display the XZ coordinates of the projection centers.

YZ Display the YZ coordinates of the projection centers.

The following settings can be made under Points:

Image numbers Display the image number to each image

Footprints will be plotted if the option *Field of view* is enabled under **Edit/Options/Visualisation/3D graphics**.

10.5.7 Orientation values

The function **Orientation values** represents the parameters of interior and exterior orientation of the selected images. It allows to verify whether the parameters are subject to unusual fluctuations. The Y-axis is scaled in the unity of the object coordinates.

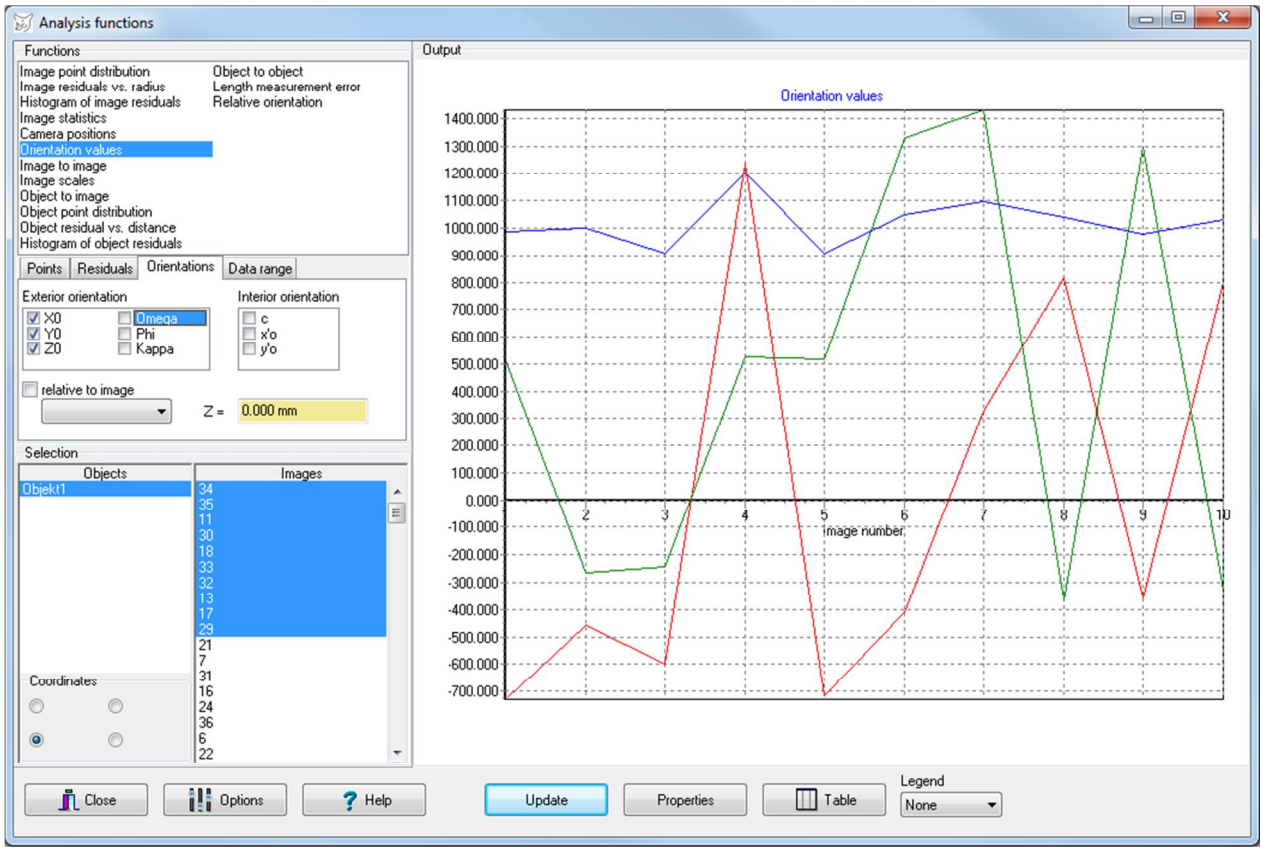


Fig. 123: Orientations values

The following settings can be made under Orientations:

Exterior orientation	Display of exterior orientation parameters
Internal orientation	Display of interior orientation parameters
relative to image	Optional entry of an image to which the differences of the parameters are plotted

10.5.8 Image to image

The function **Image to image** shows vectors between identical points of two selected images. Under Residuals a non-null scaling factor must be set.

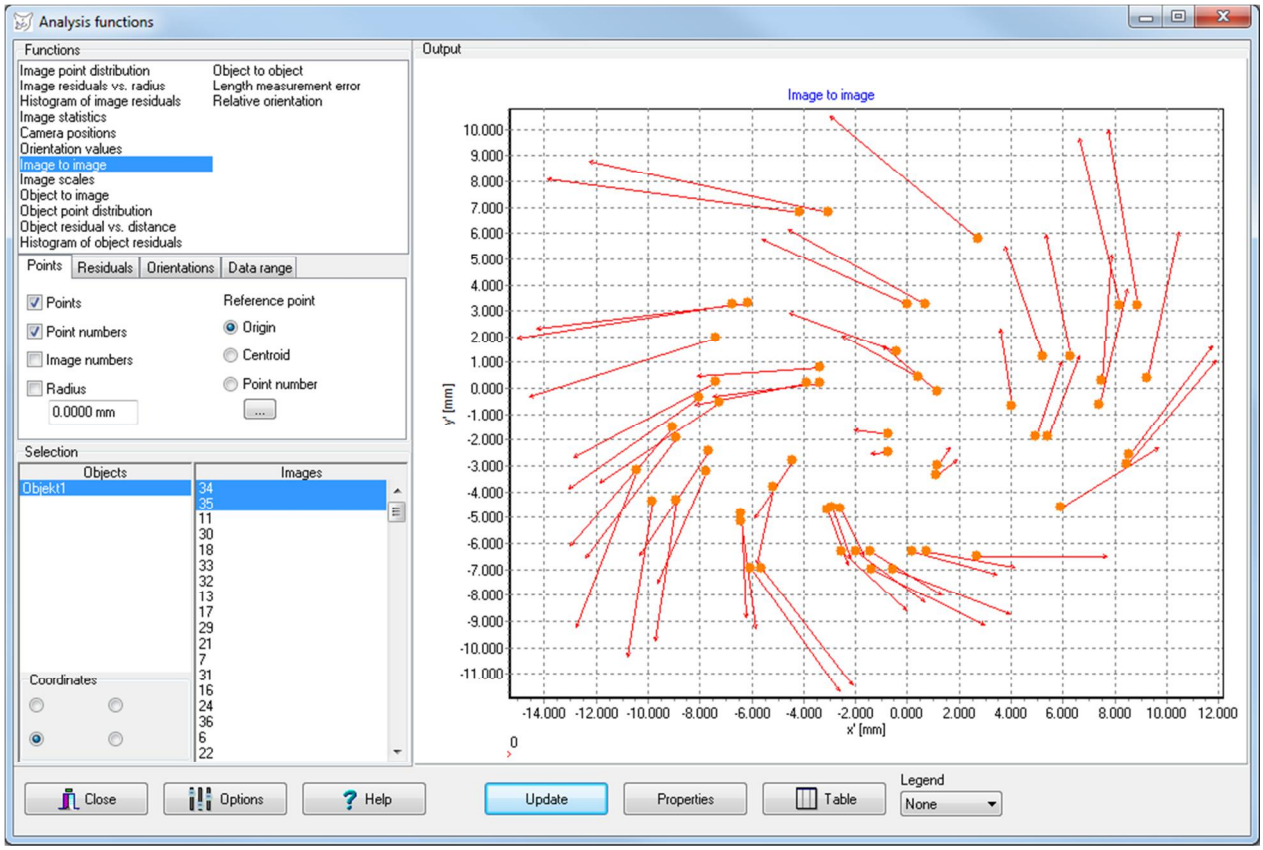


Fig. 124: Image to image vectors

The following settings can be made under Points:

Points	Display the points
Point numbers	Display the point number for each image point
Image numbers	Display the image number to every image point
Radius	Display of a circle with the given radius

The following settings can be made under Residuals:

Error vectors	The vectors are scaled with *x*. A scale bar is displayed of the vector length entered under ↔.

10.5.9 Image scales

The function **Image scales** calculates the mean image scale numbers of all selected images and all selected objects.

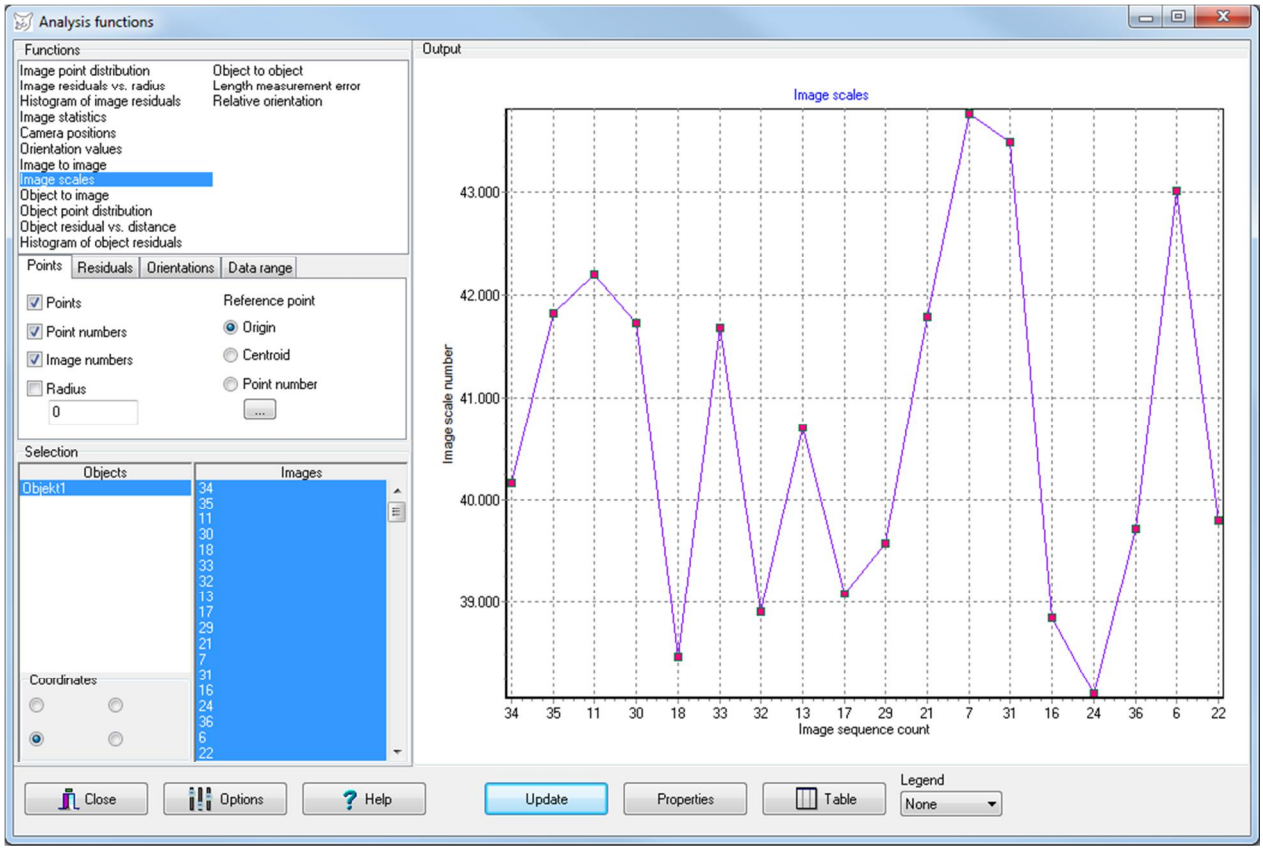


Fig. 125: Image scales

The following settings can be made under Points:

Image numbers Displays the image number on the X-axis

10.5.10 Object to image

The function **Object to image** represents the image coordinates of all selected objects in the selected image. Each object is drawn with the graphic parameters that are defined for its object coordinates. The settings can be adapted under **Objects/Object properties**. If necessary, the display of the object points must be enabled there.

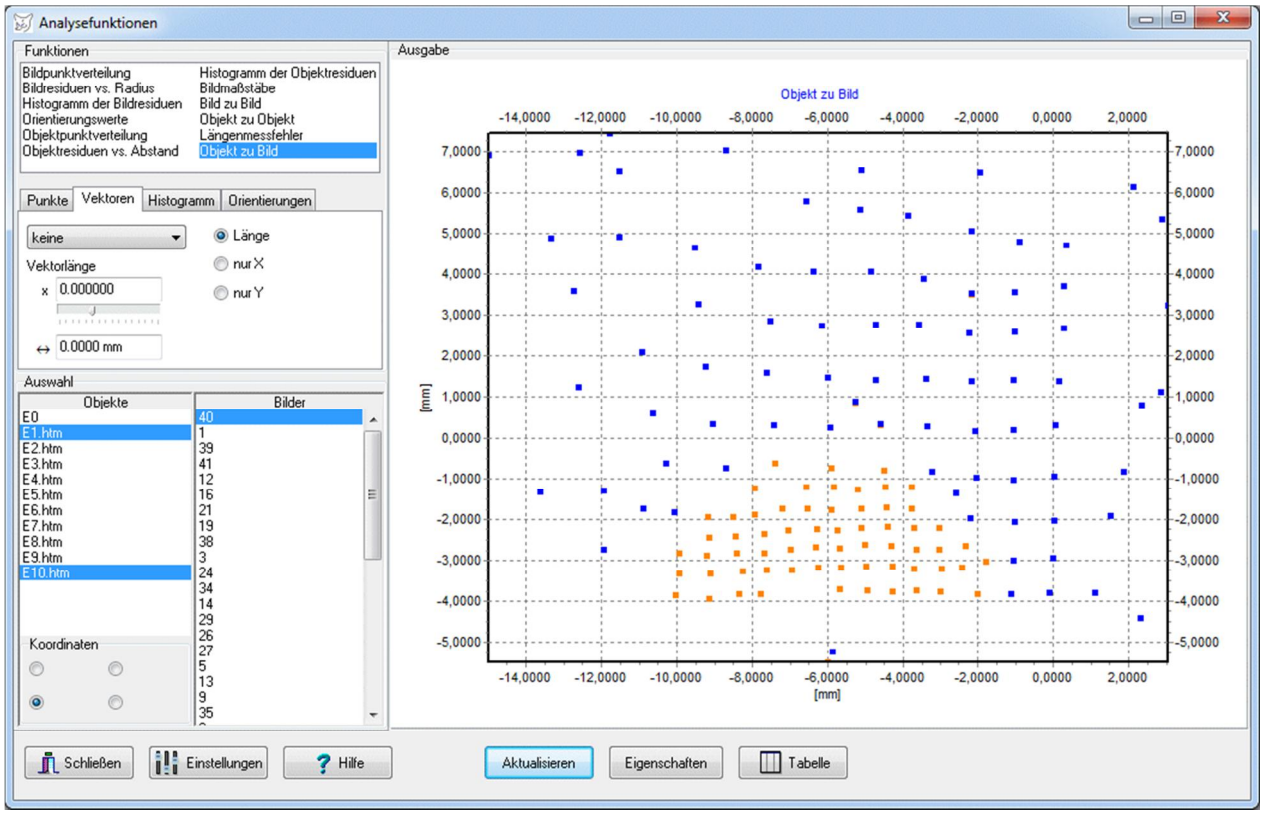


Fig. 126: Distribution of object points reprojected into the image

The following settings can be made under Points:

Point numbers Displays the point number for each image point

Radius Displays a circle with the given radius

10.5.11 Object point distribution

The function **Object point distribution** represents the stored object coordinates of selected objects in a common diagram. Each object is drawn with the graphic parameters that are defined for its object coordinates. The settings can be adapted under **Objects/Object properties**. If necessary, the display of object points must be enabled there. If polygons are available with the objects, they will be plotted if the display option under **Edit/Options/General/Graphics** has been enabled.

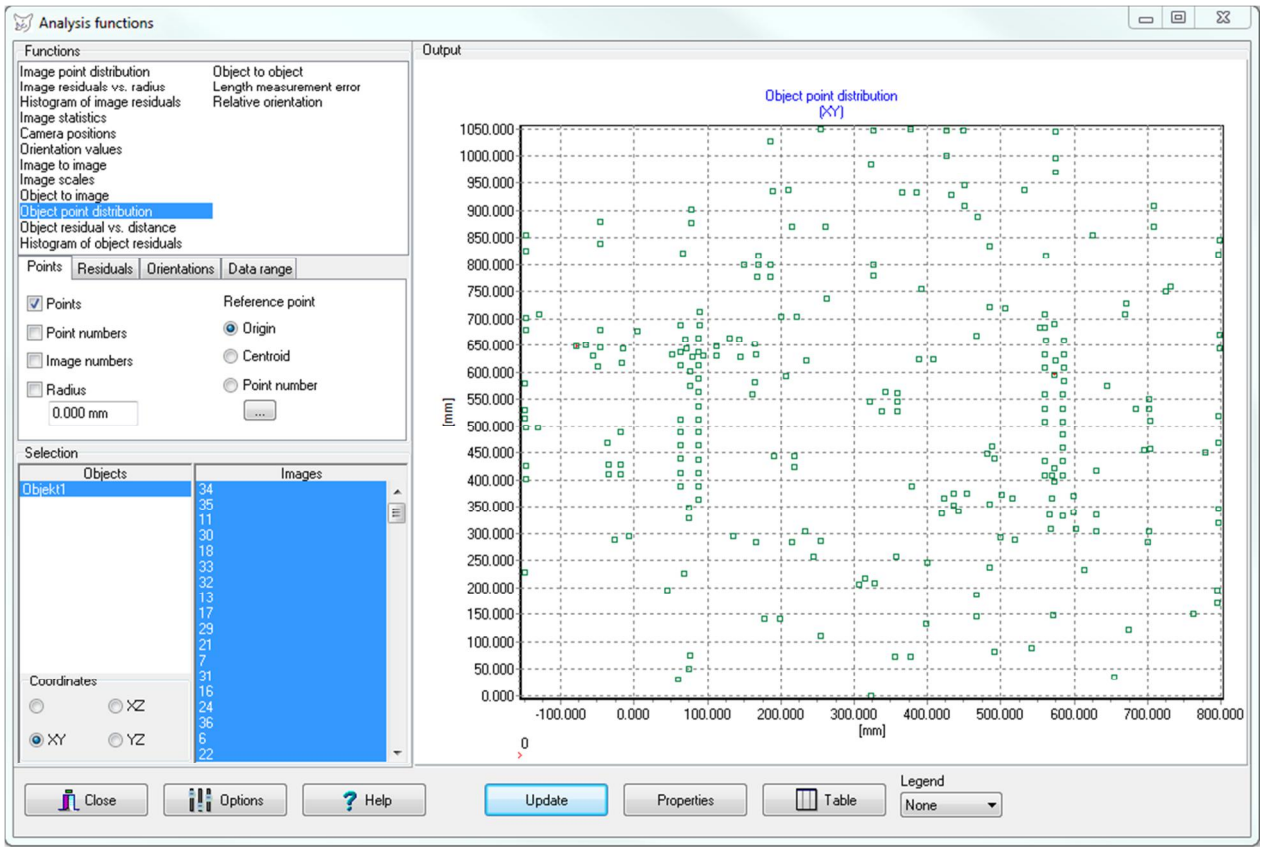


Fig. 127: Object point distribution

The following settings can be made under Coordinates:

XY Display the XY coordinates of the object points.

XZ Display the XZ coordinates of the object points.

YZ Display the YZ coordinates of the object points.

The following settings can be made under Points:

Point numbers Display the point number to each object point

The following settings can be made under Residuals:

Error vectors The vectors are scaled with *x*. A scale bar is displayed of the vector length entered under ↔.

Sigma Z The standard deviation of the third dimension of the datum plane selected under Coordinates will be shown as a vertical arrow for each point.

10.5.12 Object residuals vs. distance

The page **Object residuals vs. distance** represents the residuals (standard deviations) of the selected object points in a common diagram. It allows to check whether there is a relationship between the distance of the object points from a reference point to the residuals.

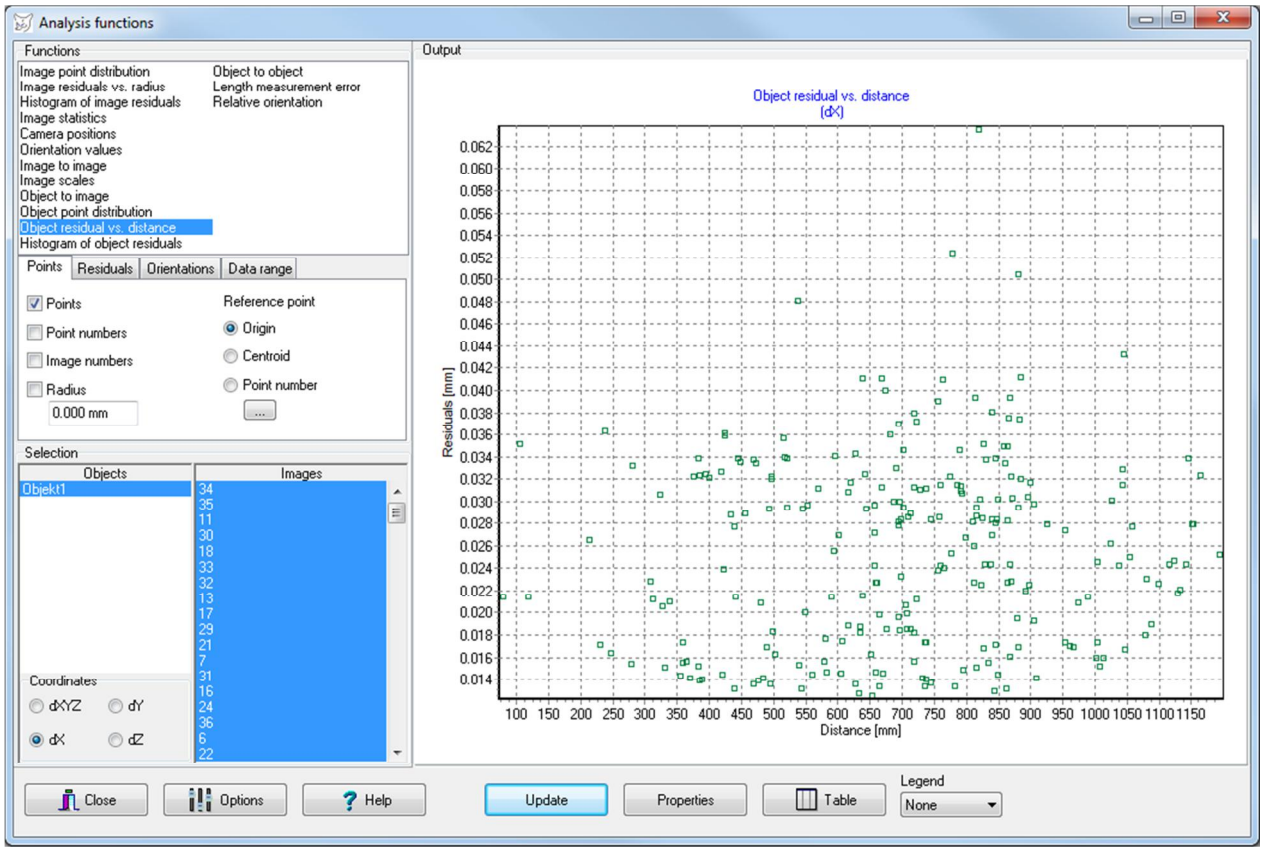


Fig. 128: Object residuals vs. distance

The following settings can be made under Coordinates:

XY	Display the XY residuals of the object points.
XZ	Display the XZ residuals of the object points.
YZ	Display the YZ residuals of the object points.

The following settings can be made under Points:

Point numbers	Display the point number to each point of the object
Reference point	3D point to which the calculated distance refers:
	Origin: origin of the coordinate system (0/0/0)
	Centroid: centroid of all object coordinates
	Point number: Selection of an object point with …

10.5.13 Histogram of object residuals

The function **Histogram of object residuals** works like the corresponding page for the histogram of image residuals, but here the standard deviations are used that are saved to the object coordinates. The standard

deviations of the selected coordinate plane are used, whereby XYZ shows the spatial vector of the deviations in X-, Y-, and Z-direction.

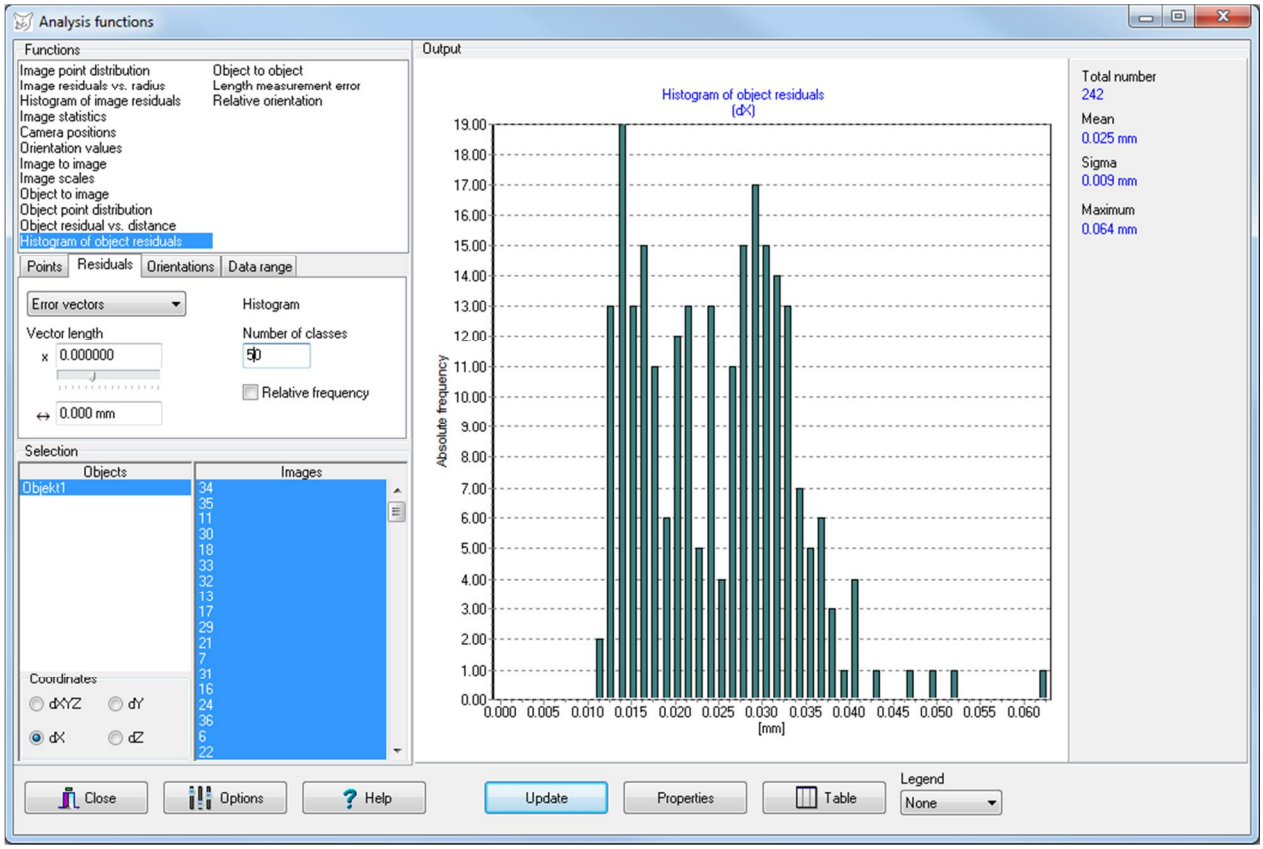


Fig. 129: Object residuals as a relative frequency histogram

The following settings can be made under Residuals:

Number of classes	Number of classes in which the residuals are separated
Relative frequency	Using the relative instead of the absolute frequency

The following settings can be made under Coordinates:

dXYZ	Residuals resulting from $v = \sqrt{sX^2 + sY^2 + sZ^2}$
dX	Residuals resulting from $v = sX$
dY	Residuals resulting from $v = sZ$
dZ	Residuals resulting from $v = sZ$

10.5.14 Object to object

The function **Object to object** shows vectors between identical points of an arbitrary number of selected objects. The vector arrows appear in the corresponding color of the object. Each object is drawn with the graphic parameters that are defined for its object coordinates. The settings can be adapted under **Objects/Object properties**. If necessary, the display of the object points must be enabled there.

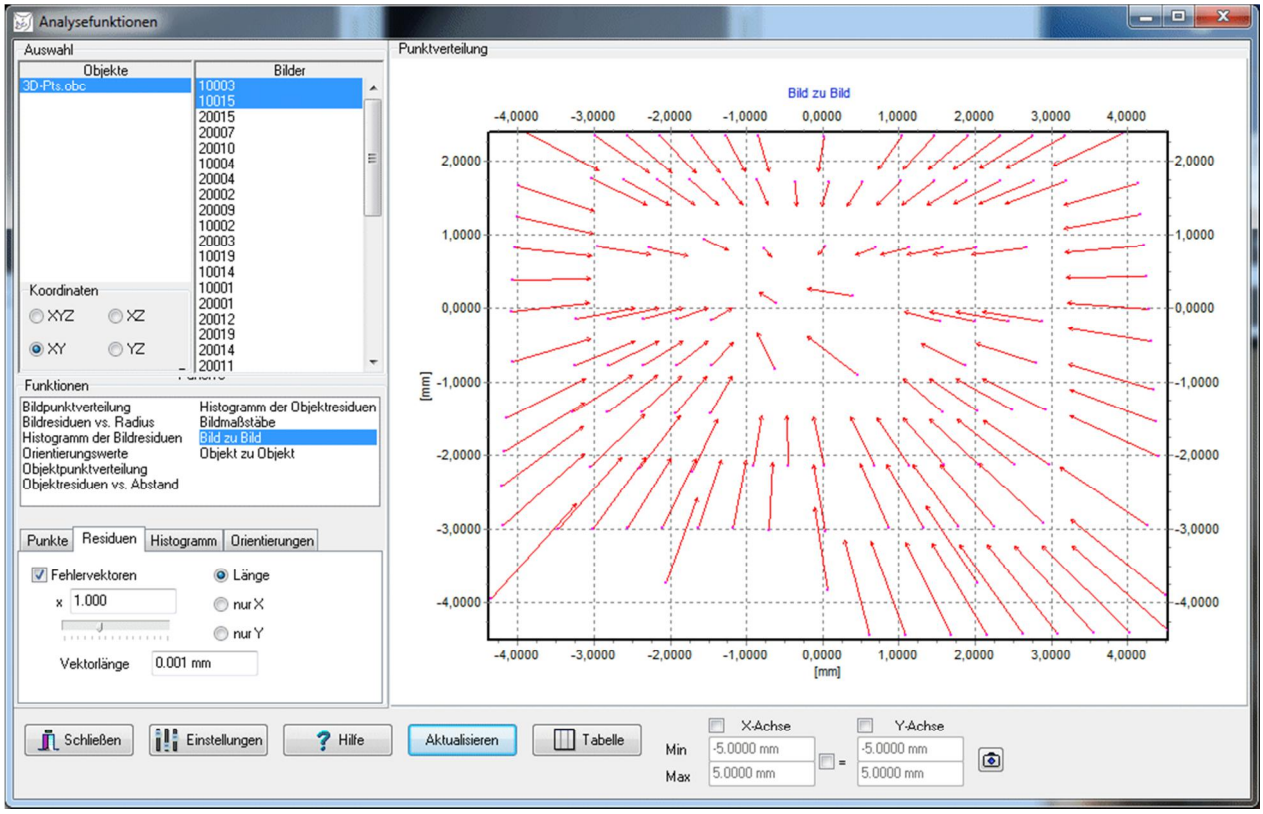


Fig. 130: Object-to-object vectors

The following settings can be made under Points:

Point numbers Display the point number for each image point

The following settings can be made under Vectors:

Error vectors The vectors are scaled with x. The endpoints of the vectors do not lie in the original positions anymore, but are distorted by the scale factor accordingly. A scale bar is displayed of the vector length entered under ↔.

10.5.15 Length measurement error

The function **Length measurement error** shows a graph of length measuring deviations between two objects. For this purpose the firstly selected object must have object points and polygons which represent the lengths to be checked (polygons between two distinct points). The second object must have object points with the same point numbers as the first object. The length measuring deviations arise from the differences between the nominal lengths of Object 1 to the measured distance of Object 2.

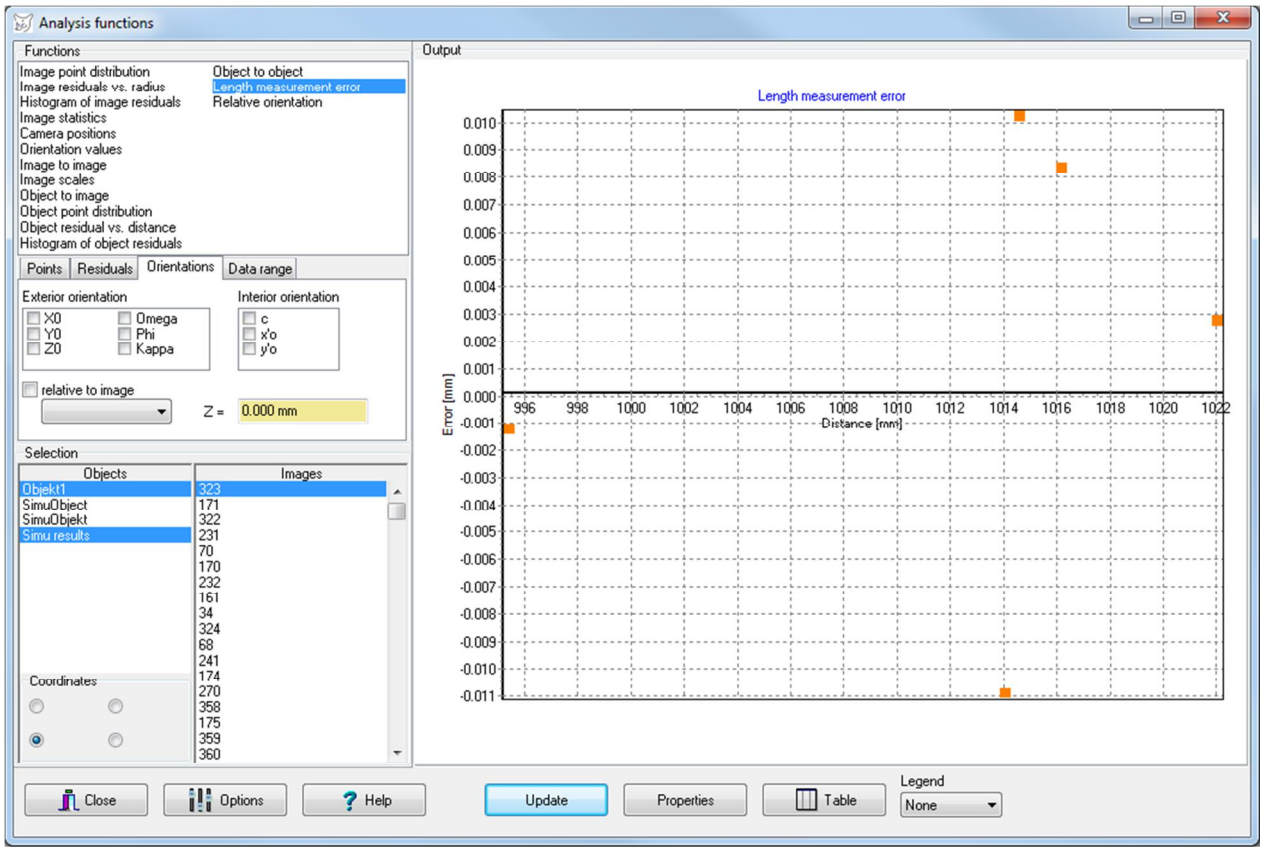


Fig. 131: Diagram of length measurement errors

10.5.16 Relative orientation

The function **Relative Orientation** represents the parameters of interior and relative orientation of the selected stereo models. The orientation data refer to a relative orientation of dependent image pairs. The Y-axis is scaled in units of the model coordinates and/or rotation angles.

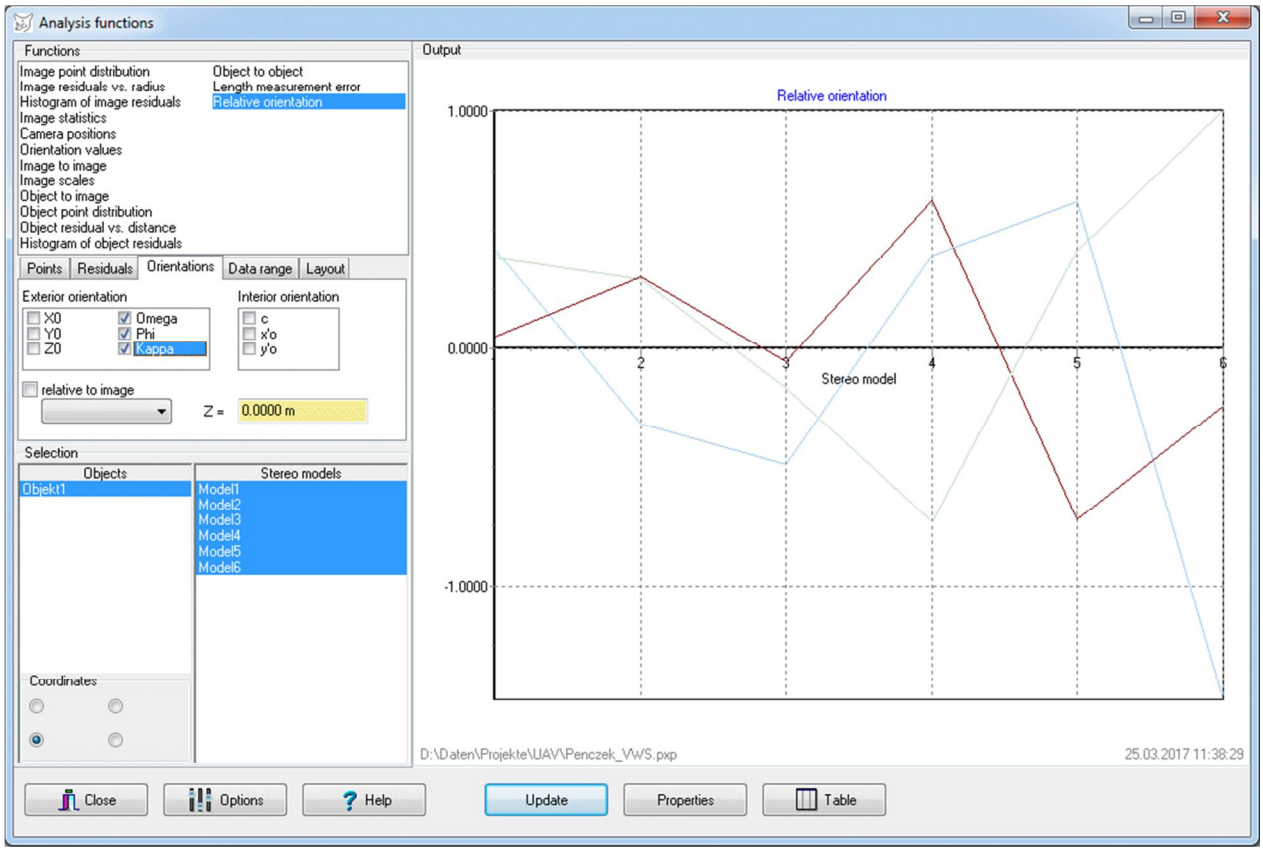


Fig. 132: Relative orientation

The following settings can be made under Orientations:

Exterior orientation Display of relative orientation parameters

Internal orientation Display of interior orientation parameters

relative to image Optional entry of a stereo model to which the differences of the parameters are plotted

11 Menu Simulation

The menu **Simulation** provides functions for processing marked modules are available.

11.1 Image coordinates

Menu:	Simulation → Image coordinates
Precondition:	Existing image and activated object

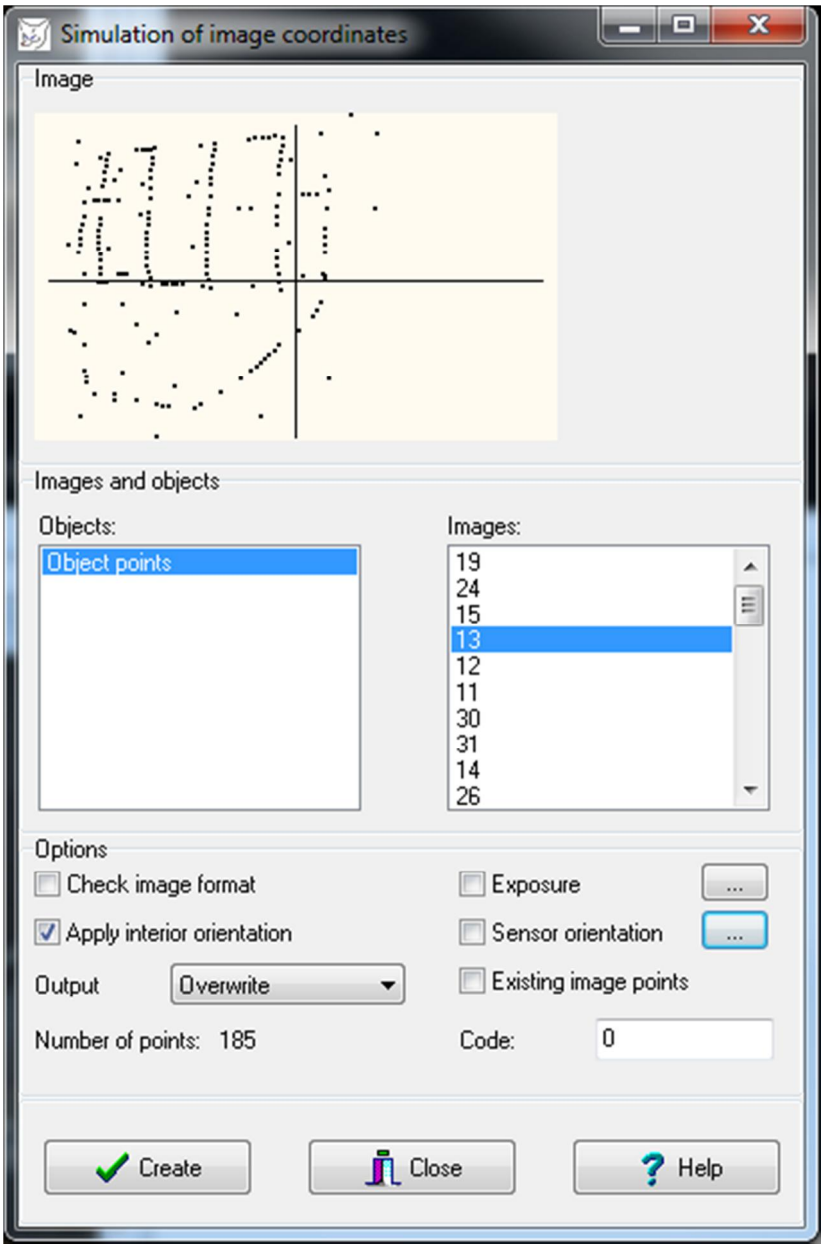


Fig. 133: Simulation of image coordinates

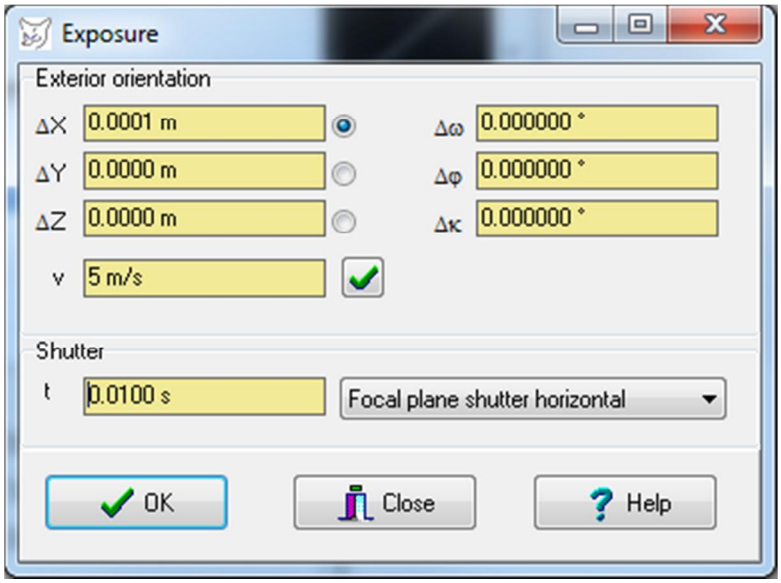
The function **Image coordinates** is used for the simulation of image coordinates from given 3D object points as well as parameters of interior and exterior orientation of an image using the collinearity equations. After the function call, a window pops up where a 3D object (*Objects*) can select which object coordinates should be converted to image coordinates for the images marked in the list *Images*.

Under Image the expected image points are graphically displayed.

If the option *Test image format* is activated, only image points will be saved within the image format that corresponds to the defined sensor format of a camera associated with the image.

With the option *Apply interior orientation* the simulated image coordinates will be modified according to the interior orientation parameters associated with an image. Thereby the image coordinates correspond to the measured image points, i.e. they include all influences of principal point shift and distortion.

With the option *Exposure* the influence of a shutter can be simulated. An input dialog will be opened with the button [...] where shutter characteristics can be entered. It is assumed that the exterior orientation changes linearly during the exposure period over a defined interval. Depending on the position of a simulated image point, the corresponding exterior orientation is calculated and applied in the collinearity equations.



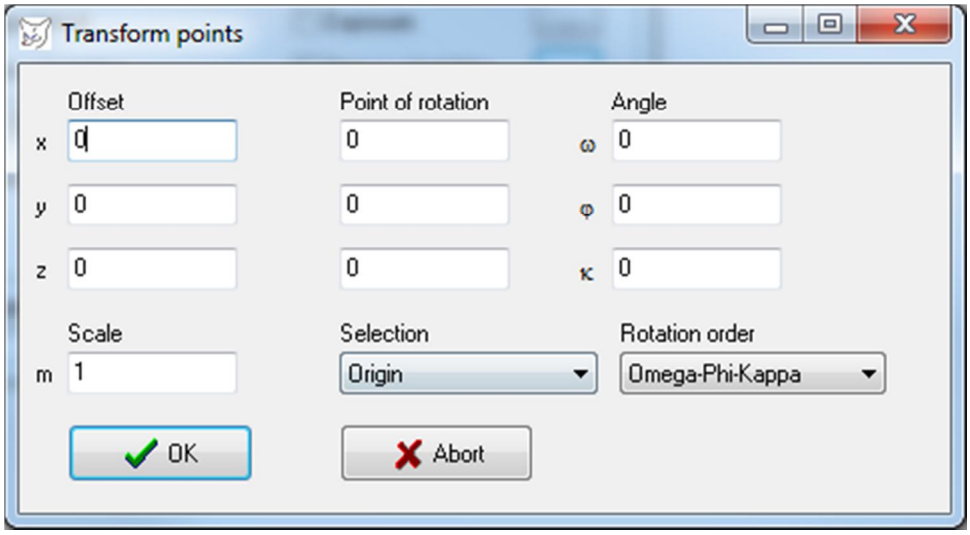
Exterior orientation:

ΔX etc.:	The specification of expected changes of exterior orientation parameters during the exposure time
v:	The movement speed of the camera platform. With the button ✔ a translation value Δ is calculated from *t* and *v*.

Shutter:

t:	Exposure time *t*
[Shutter type]:	*No shutter*: no effect on simulated image coordinates *Focal-plane shutter horizontal*: horizontally moving slit *Focal-plane shutter vertical*: vertical moving slit

With the option *Sensor orientation* the spatial location of an image sensor can be changed in the camera. An input dialog will be opened with the button [...] where further characteristics of spatial transformation can be entered.



Offset: Sensor displacement in x-, y -, or z-direction (mm)

Point of rotation: Coordinates of the point of rotation predefined point under *Selection*

Angle: Sensor rotation with three spatial angles around the chosen point of rotation.

Scale: Scale of transformation

The button [Existing image points] is used to create only such point numbers that already exist as image points to a respective image. The previously saved image coordinates will be overwritten.

With the option *Output* the saving of calculated image coordinates is specified.

Overwrite: Overwrites possibly existing image points of the current image.

Append: The newly computed points are appended to the already existing image points; it can lead to the duplicate point numbers.

Export: Opens a file dialog to set an output file and an output format for simulated image coordinates. The image coordinates are only exported but not saved to the current image. The formats correspond to the function **Project/Export/Image coordinates**.

With the button [Create] the image coordinates are calculated and saved to the participating images. The simulated image points will receive the code entered under *Code*.

11.2 Noise

Menu:	Simulation → Noise
Precondition:	Loaded project

The function **Noise** is used for adding statistical noise to image coordinates, object coordinates, or parameters of exterior and interior orientation. Thereby, random distributed numerical values defined under Noise are added to the input values. Here, a normal distribution of random numbers is set by default. The input objects which should be affected are set under Selection.

Mode defines an input object that should be noised:

Image coordinates Adds noise x', y' to the image coordinates of selected images.

Object coordinates Adds noise X, Y, Z to the object coordinates of selected objects.

Exterior orientation Adds noise to the exterior orientation coordinates of selected images for translations with X0, Y0, Z0 and for rotation angles with ω, φ and κ.

Interior orientation Adds noise to the interior orientation parameters of selected images with *c* (principal distance), *x*- and *yo* (principal point location) as well as optional the distortion parameters. The noise ranges and activation of distortion parameters occur via the button [...].

The calculation is started with [Apply]. Thereby, the existing values of an input object will be overwritten without request and cannot be restored after.

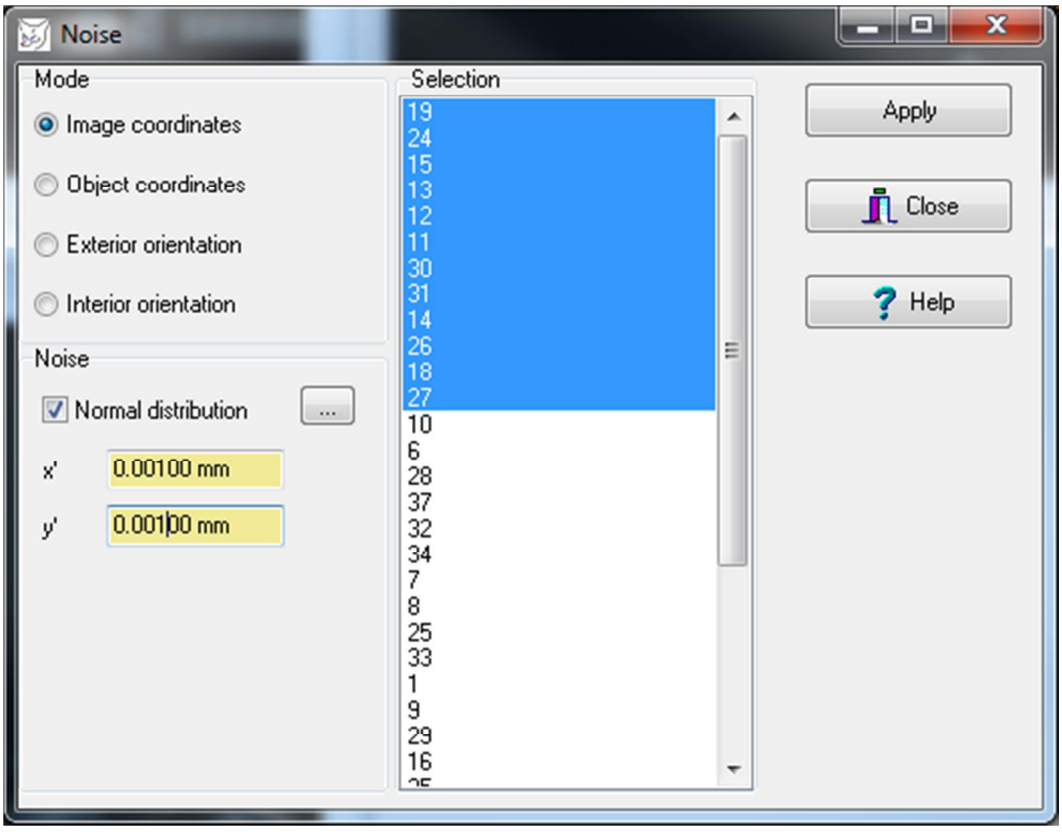


Fig. 134: Adding noise to input values

11.3 Forward intersection

Menu:	Simulation → Forward intersection
Precondition:	Min. 2 images and activated object

The function **Forward intersection** is used for the simulation of spatial forward intersection by Monte-Carlo simulation.

Initially, at least two images are marked under Images, from which the forward intersection will be calculated. Thereto an object with saved 3D coordinates will be selected under Objects, which coordinates serve as target coordinates of the object points. If the option *Create image coordinates* is activated, new image coordinates are calculated from these 3D coordinates for a marked image, whereby *Distortion* can be optional applied. The function *Correct distortion* determines, whether the calculated or measured image coordinates should be corrected according to distortion before the calculation of forward intersection. Deviations of measured lengths can be simulated with the option *Length measurement errors*.

In the Simulation a predetermined *Number of simulations* is calculated, whereby the input data for forward intersection can be made noisy in each iteration. The data, which should be made noisy, can be selected under Noise, the noise range can be defined under Options.

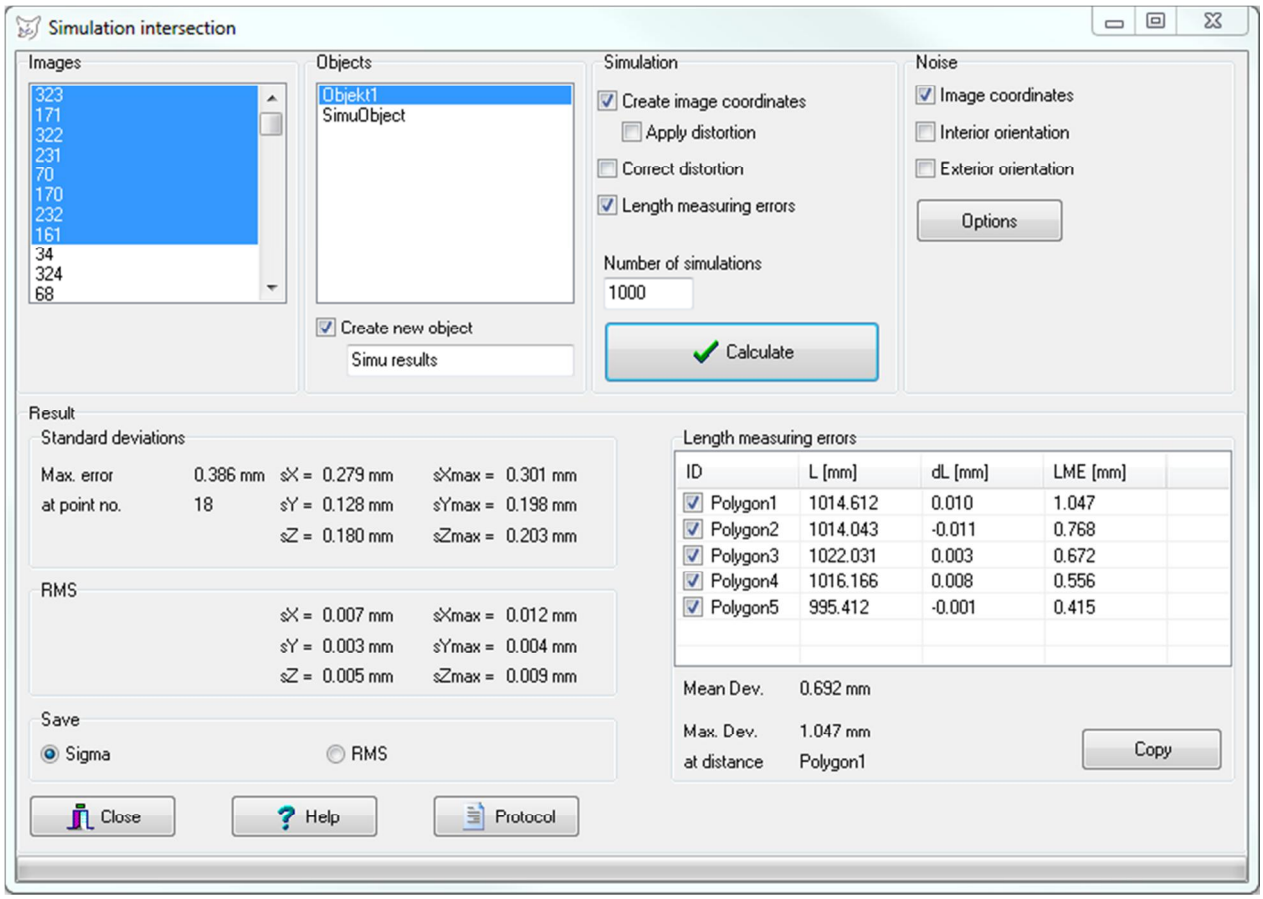


Fig. 135: Simulation of spatial forward intersections

After the simulation process, the average and maximum deviations of calculated 3D coordinates for the target object are displayed under Result. The average standard deviations are calculated as Standard deviations on all points with respect to the mean of object coordinates, while the RMS values represent the root mean square errors to the original coordinates of the target object.

If the option *Length measurement errors* is activated, then all polygons with exactly two polygon points belonging to the selected object will be listed under Length measurement erros. By activating the check box of the desired polygons, the distances are defined for which length measurement deviations will be calculated. Thereby the distances between corresponding object points are calculated in each simulation iteration and compared with the known nominal length. The nominal length is displayed under *L*, then average length deviation under *dL* and the maximum length measurement error under *LME*. The table data can be copied with Copy to the Windows clipboard and from there directly inserted into Excel.

11.4 Resection

Menu:	Simulation → Resection
Precondition:	Existing image and activated object

The function **Resection** is used for the simulation of space resection by Monte-Carlo simulation.

At first, an image is selected under Image, which current data are applied for the simulation of interior and exterior orientation. Under Objects an object with saved 3D coordinates can be selected, which serves as reference points for space resection. Particular points can be selected in the coordinate list. At least four points are required for a space resection.

The noise ranges of reference object coordinates and corresponding image coordinates are set under Simulation. If the option *Create* has been activated, new image coordinates will be calculated for a marked image respectively to the 3D coordinates, whereby *Distortion* can be applied optionally. If the option *Create* is deactivated, the image coordinates must already exist for a selected image. The noise ranges for camera data are defined in Options.

Noise of camera data (interior orientation) is defined under Options. If is shall be considered in simulation, the options *Apply distortion* and *Noise to camera data* must be activated.

In the Calculation, a predetermined *Number of simulations* is calculated for space resection, whereby statistical noise is added to the input data in each iteration. A log file can be optionally created.

After the simulation process, the average and maximum deviations of calculated orientation data are displayed under Results. If the option *Mean values* is activated, the standard deviations displayed under *Sigma* are calculated with respect to the mean orientation values of all iterations. In contrast, the option *Nominal - Measured* calculates the root mean square deviations with respect to the nominal values from a selected image.

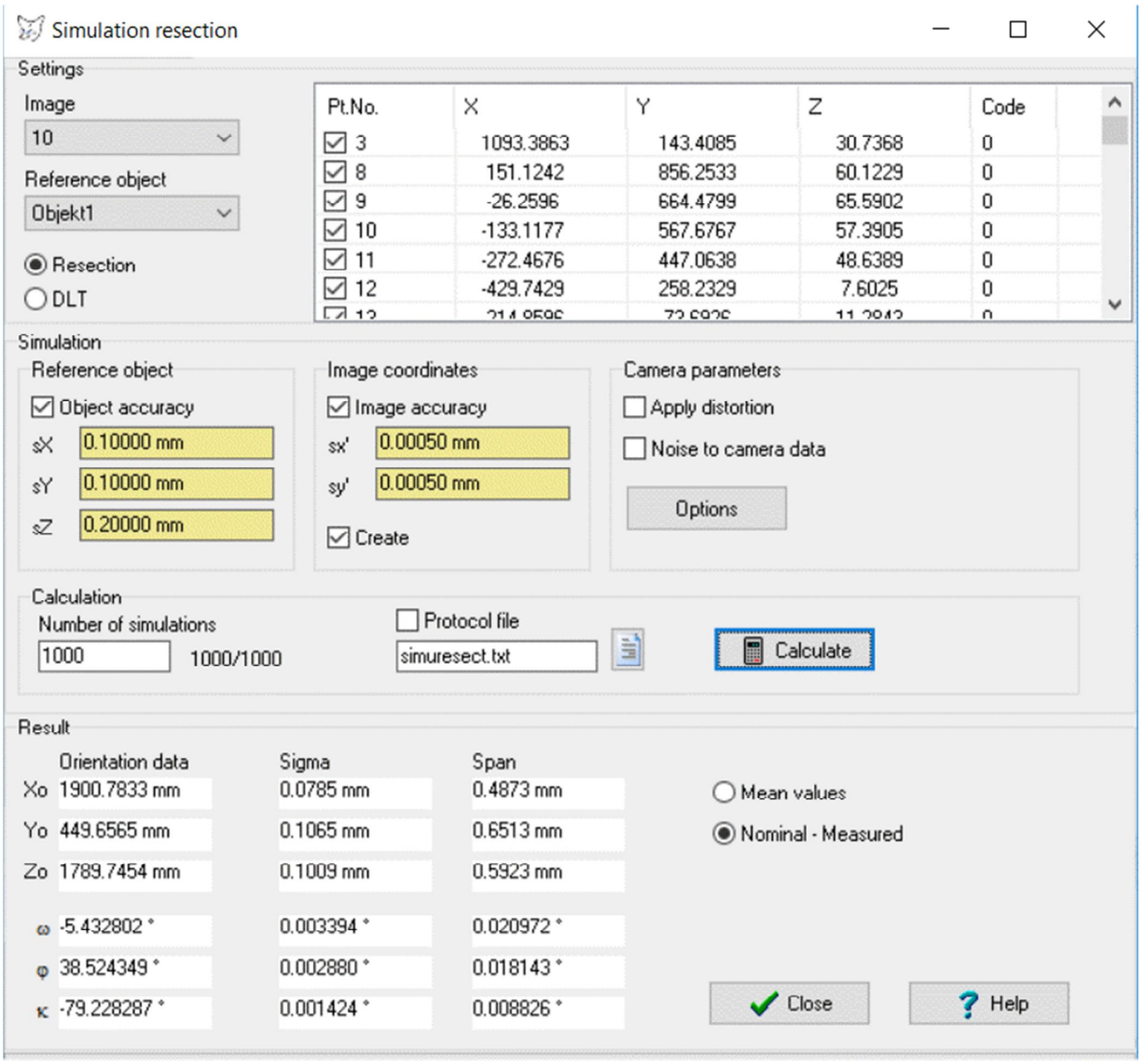


Fig. 136: Simulation of space resection

11.5 6DOF

Menu:	Simulation → 6DOF
Precondition:	Existing image and activated object

The **6DOF** function is used for the simulation of 6DOF-calculations between two visible objects in a single image using Monte-Carlo simulation. Two 3D objects (reference and locator object) with at least three (better four) XYZ points are required for this function each given in a local coordinate system defined on the respective object. Furthermore, an image object must be present with the data of interior and exterior orientation. The program calculates the six degrees of freedom (6DOF) of relative position between reference and locator object, and transforms the coordinates of a locator probe tip into the reference system.

The process of 6DOF-simulation works as follows:

1. 3D transformation of a locator object with the nominal 6DOF values
2. Calculation of image coordinates of the reference object
3. Calculation of image coordinates of the transformed locator object
4. Calculation of space resection for the reference object with calculated image coordinates from step 2
5. Calculation of space resection for the locator object that contains the original object coordinates of a locator and calculated image coordinates from step 3
6. Calculation of 6DOF parameters from two space resections
7. Transformation of optional probe tip coordinates from the locator system in the reference system with the calculated 6DOF parameters.

Following input data are defined in Specifications:

Image	Selection of an image using the data of interior and exterior orientation
Reference object	Selection of a reference object with local 3D points that serves for the simulation of image coordinates (step 2) (*For image coordinates*) on the one hand and as 3D object for space resection (*for object coordinates*) on the other hand. If the same object will be chosen for image and object coordinates, then non-zero transformation values should be entered under *6DOF nominal values*. However, if another object is specified by *Image coordinates*, it should preciously be spatially transformed in a position, which corresponds to the exterior orientation system of a camera.
Locator object	Selection of a locator object with local 3D points, which also is used for the simulation of image coordinates (step 3) (*for image coordinates*) and as 3D object for space resection (*for object coordinates*).
Probe tip	Object point selection of a locator object, which local coordinates are transformed using the determined 6DOF parameters. Only the locator points with a non-zero point code are displayed here.
6DOF nominal values	The locator object is transformed with the parameters entered here. The transformed locator object is then used for the calculation of image coordinates.

The noise ranges for Monte-Carlo simulation are entered under Simulation. If activated, the entered values for *object accuracy* and *image* measurement *accuracy* of reference and locator object will be applied.

Under Camera parameters it can be set, whether distortion of the corresponding camera will be applied with calculation of image coordinates and whether the interior orientation parameters should be made noisy. The noise ranges are defined under Options.

The Calculation of Monte Carlo simulation is executed with the entered number of passes. Optionally, an *Output logfile* can be generated with the specified file name.

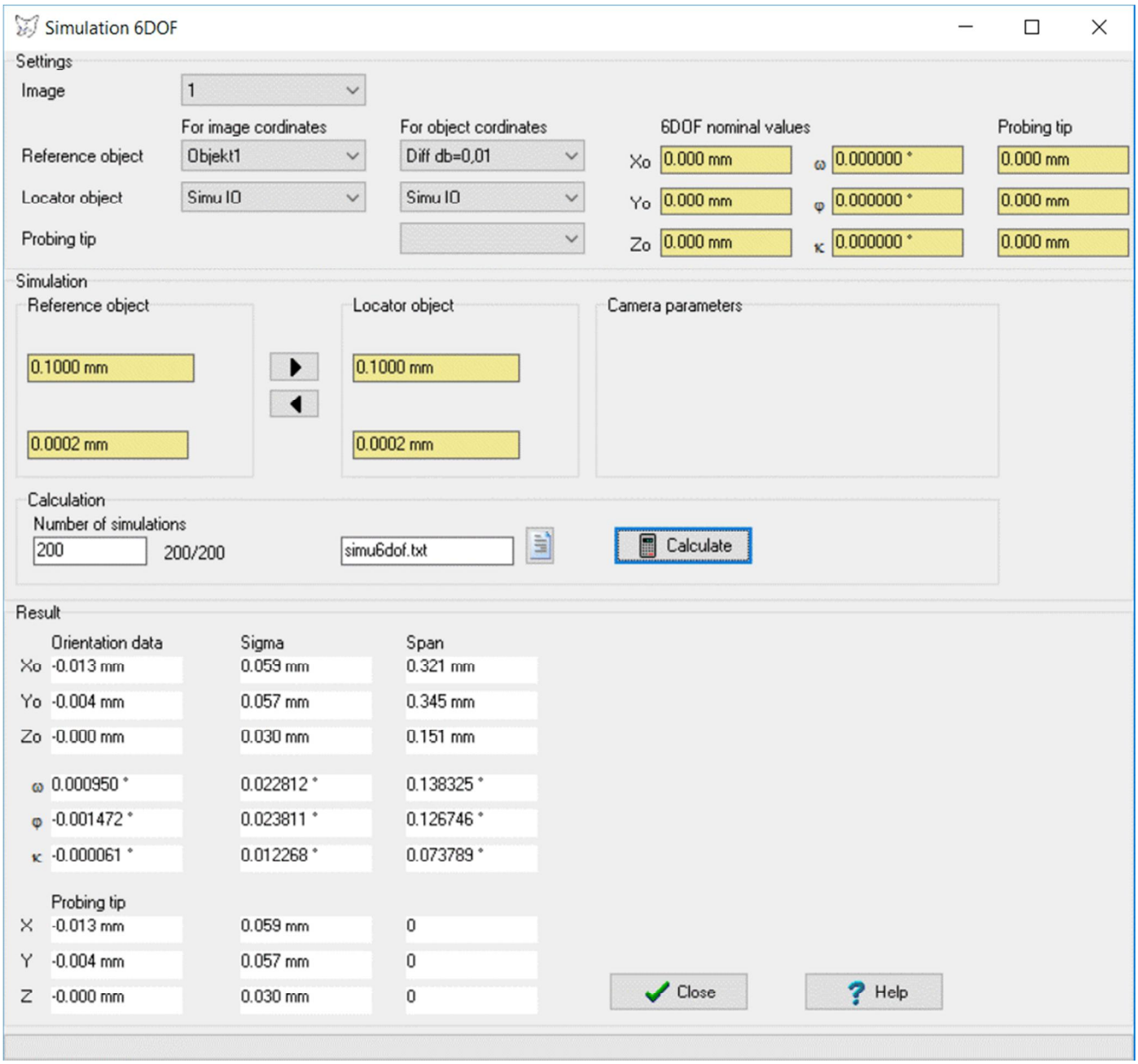


Fig. 137: Simulation of 6DOF calculations

Calculate starts the simulation. A log file can be displayed under Output log. The calculated *Orientation values* are displayed with its value, standard deviation (*Sigma*), and maximum deviation (*Span*). The same can be applied for the simulated coordinates of the probe tip.

11.6 3D transformation

Menu:	Simulation → 3D transformation
Precondition:	Activated object

The function **3D transformation** serves for the simulation 3D-similarity transformation between two objects by Monte-Carlo simulation. The function requires two 3D objects (*Source* and *Target object*) with a minimum of three identical XYZ points each. The function complies with 3D similarity transformation under **Objects/3D transformation**.

Under Simulation, following input data are defined:

Number	Number of simulation passes (unlimited, recommendation: >5000)
Sigma xyz	Noise range of xyz-coordinates of a source object
Sigma XYZ	Noise range of xyz-coordinates of a target object

Calculate starts the simulation. The transformation parameters calculated per simulation run are saved in the file SimuTrans.txt. This file contains details of minimum, maximum, mean and standard deviation of each parameter. At the end of simulation, the calculated mean transformation parameters are displayed in the result fields.

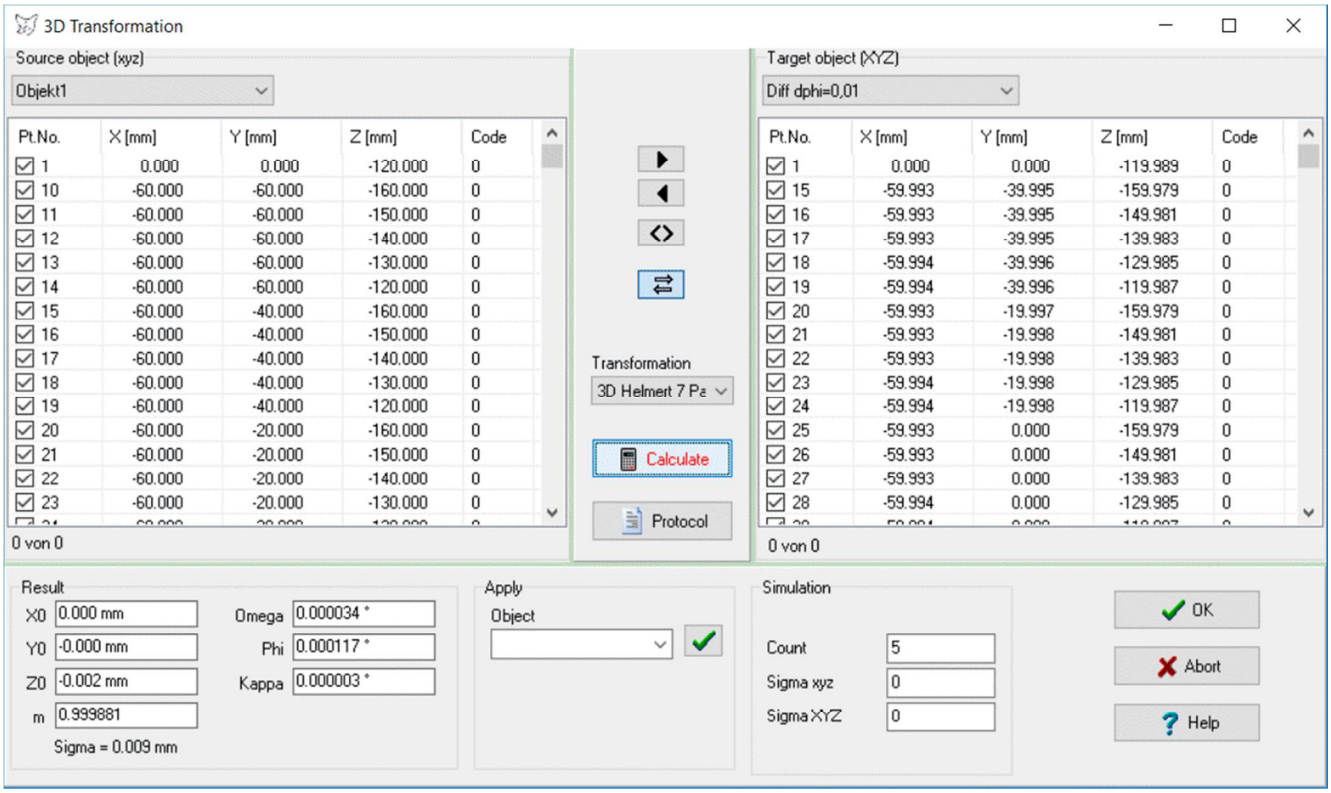


Fig. 138: Simulation of 3D transformations

11.7 Ellipse eccentricity

Menu:	Simulation → Ellipse eccentricity
Precondition:	Existing image and activated object

The function **Ellipse eccentricity** is used to simulate the effect of ellipses eccentricities to an image and in object space. This function requires 3D object as well as at least one image with the data of interior and exterior orientation.

The module calculates the corresponding image coordinates based on given 3D object coordinates. For each object a space circle of a given radius and a spatial orientation is assumed which boundary points are strictly projected into the image space, where they get the form of an ellipse. The difference between the center point of a best-fit ellipse and the projected object point (circle center) shown in the image results in the eccentricity of the ellipse. Through a subsequent forward intersection through all selected images the circle centers as well as the ellipse center point will be calculated as a 3D point. This 3D point must match with the given 3D object point when using the circle centers, while the 3D ellipse center point can deviate due to the eccentricity of the ellipse.

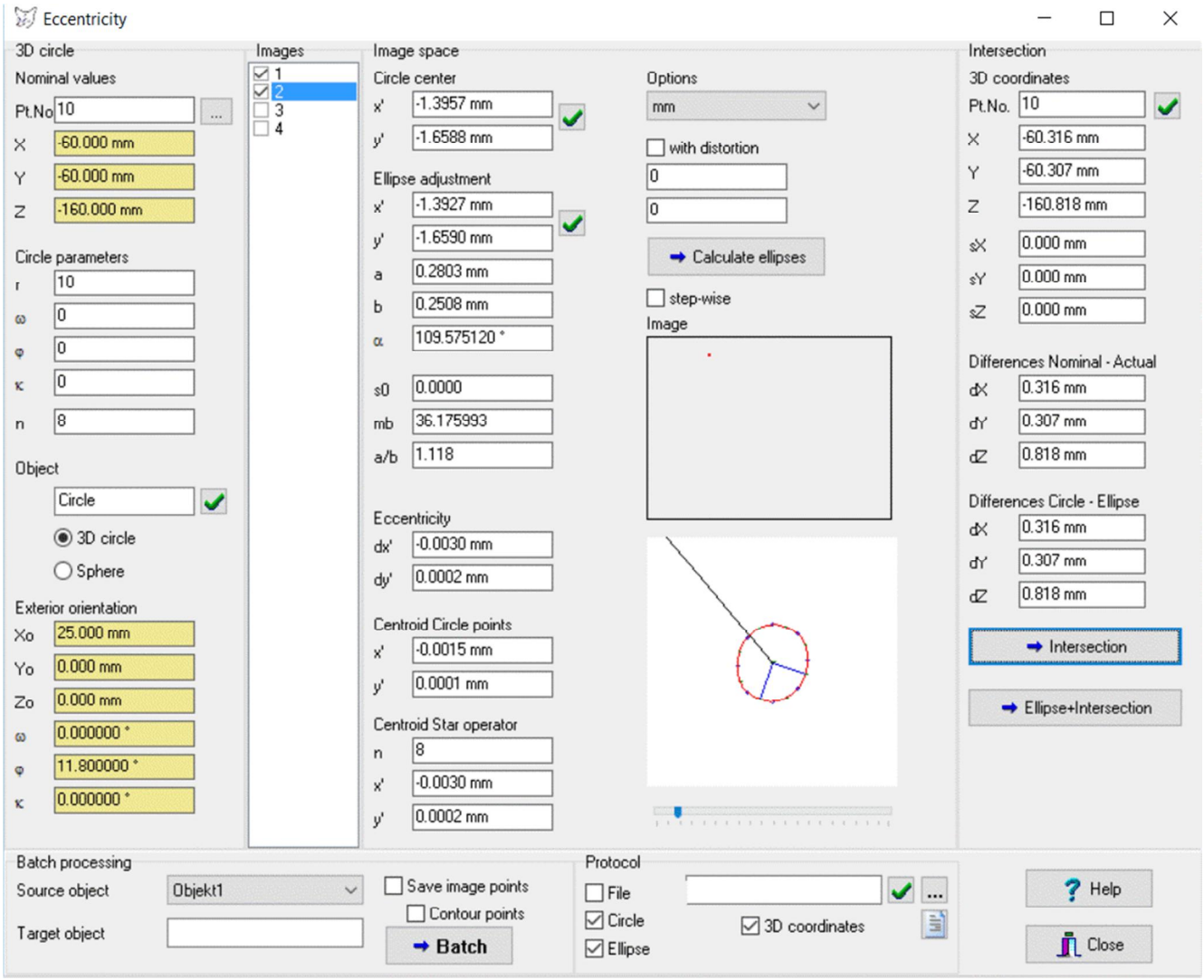


Fig. 139: Simulation of ellipses eccentricity

Under 3D circle, following input data are defined:

Pt.No., X, Y, Z 3D point data for the center of a space circle. With the button [...] a point from a current object can be selected.

Circle parameters: Data of 3D circle with radius *r*, spatial orientation angles ω,φ,κ and the number *n* of boundary points to be generated on the circle.

Object: Name of a new 3D object that contains the *n* 3D coordinates of the circle outline as object points. The object can be created with the button  .

Images are selected under Images, for which the simulation should be calculated. With a popup menu all images can be selected or the selection can be changed.

Under Image space, the ellipse points mapped from the contour points of a given space circle are calculated and a best-fit ellipse can be determined again. The calculation starts with the button [Calculate ellipses]. The top graphic shows the point location in the image format, the bottom graphic represents the calculated ellipse. The zoom factor of this graphic can be changed with the slider.

Circle center Image coordinates for the projected center of the 3D circle.

Ellipse adjustment: Result of the ellipse adjustment with center *x'*, *y'*, semi-axes *a*, *b*, rotation angle α as well as s_0 of the adjustment.

s0 Standard deviation Sigma0 of ellipse adjustment.

m Image scale number of a point, which is a quotient between the space circle radius *r* and long semi-axis a of the ellipse.

a/b Quotient of long semi-axis *a* and short semi-axis *b* of the ellipse.

Eccentricity: Difference *dx* and *dy* of the projected circle center and the ellipse center.

Centroid Circle points: Centroid of image coordinates of the circle boundary points.

Centroid Star operator: Centroid of image coordinates of the ellipse points, which results from a simulated measurement with “star”-operator.

Options: The output unit of image coordinates can be specified here. If the unit *Pixel* has been selected here, the metric image coordinates are transformed with an associated pixel-size.

Under Forward intersection, the 3D coordinates are calculated from the center of the projected space circle and the projected ellipse. The calculation starts with the button [Intersection], which uses all images that have been selected on for an ellipse calculation. The button [Ellipse+Intersection] calculates the ellipses and performs the forward intersection.

3D coordinates Object coordinates and standard deviations when using the ellipse centers.

Difference Nominal – Actual: Coordinate differences between the 3D coordinates defined under *3D circle* and the result of forward intersection.

Difference Circle – Ellipse: Coordinate differences between the two forward intersections, which have been calculated once with the projected circle centers and once with computed ellipse centers.

The total calculation for all selected 3D points of an object is performed under Batch processing. The calculation starts with the button Batch.

Source object Object with a list of 3D points.

Target object: Optional new 3D object, for which the calculated 3D coordinates are saved. If an entered name exists already in the object list, the associated object will be deleted or overwritten with the newly computed coordinates.

Save image points: If this button is activated, the calculated ellipse center points x, y and the eccentricity to the projected circle center will be saved under sx, sy as image coordinates to the corresponding image.

11.8 Simulated images

Menu:	Simulation → Simulated images
Precondition:	Existing image and activated object

The function of **Image simulation** is used for the generation of synthetic images for an object that is represented by a TIN and an image, which content (texture) should be transferred into the simulated image. The result image has the entered data of interior and exterior orientation, so that a view on an object from a different direction is generated.

The 3D objects with existing TIN appear under Objects. If no meshing (triangles) is available for this object, it can be generated using the function **Objects/Meshing**. An object should be selected in the list, which TIN represents the object surface.

Under Texture image the list of images in the project appears, for which a bitmap is loaded. Here, the image is selected, which content is to be transferred into the resulting image.

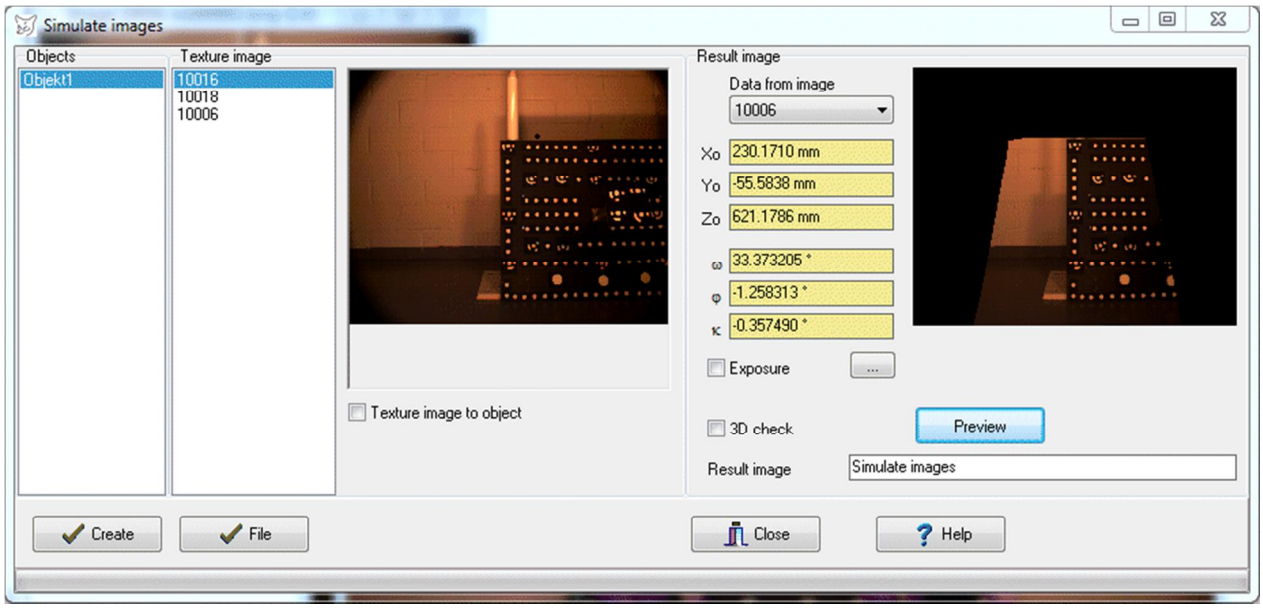


Fig. 140: Simulation of images

The exterior orientation data of a resulting image are specified under Result image. The interior orientation data are taken from an image, which should be selected under *Data from image*. The exterior orientation data can be overwritten interactively. A selected image must have a saved bitmap.

3D check The overall list of triangles is scanned completely for image calculation. If this option is deactivated, the first found triangle will be used. The image calculation is significantly faster in deactivated mode (see below).

Exposure Optionally, a shutter effect can be simulated here. Thereto, an input dialog will open with the button ..., where the further characteristics can be entered.

Exterior orientation: Specification of expected parameter changes of exterior orientation and velocity *v* of a camera platform during exposure time.

Shutter: Specification of exposure time *t*, as well as a shutter type.

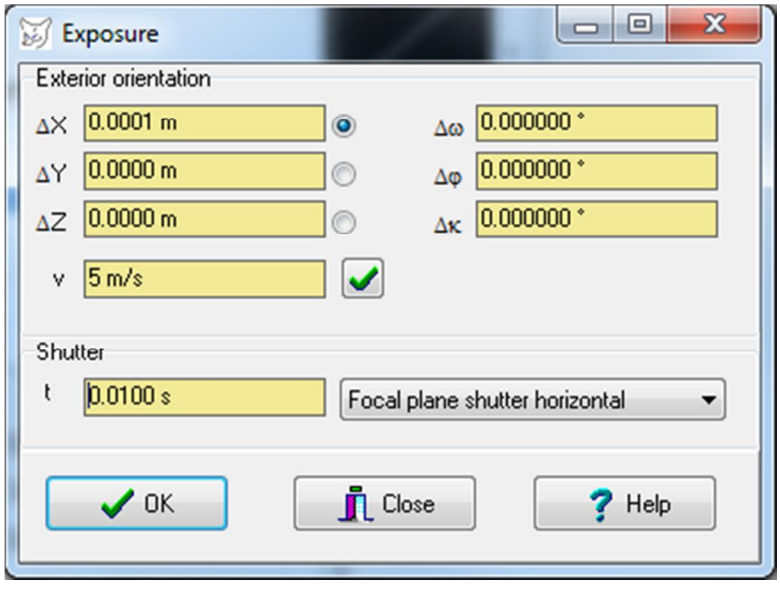


Fig. 141: Definition of exposure parameters

The button Preview creates a downscaled preview image of the result. Thereby, all pixels of a resulting image are intersected with the TIN using the procedure of monoplotting. The resulting 3D surface point is reprojected into the texture image and the existing color values are transferred into the result image. Areas lying outside of the texture image are displayed in red in the preview.

With Create, the result image is calculated with the resolution of the input image. This process requires a significant processing power and can take several hours. The required time depends mainly on the number of triangles. If the option *3D check* is activated, all triangles are considered and such surface point will be used which has the shortest distance to the camera. Otherwise, the first found triangle intersection is taken, like in case of so-called 2½D surfaces without undercuts. The final image is stored as a new image object in the image list.

The button File reads a control file, where any number of images can be processed in batch mode. Each image can have its own orientation data, as well as an associated TIN. Again, the created images are saved as image objects in the image list.

The format of a control file (file extension *.txt) is:

```
# Control file for image simulation
NewImage=NewName.jpg
  IntOri=example.ior
  ExtOri=example.eor
  Triangles=example.stl
  TextureImage = dcs456.jpg
EndImage
NewImage=NewName2.jpg
  IntOri=example2.ior
  Triangles=example2.stl
  TextureImage = test.bmp
EndImage
```

In this example, two new images are created, whereby interior orientations and TIN are different, while the same exterior orientation data are applied. The data of interior (IntOri) and exterior (ExtOri) orientation are read from AICON-format files. The triangles (triangles) are read in the STL format. The applied texture images are entered with its directory path, image formats are freely selectable.

12 Menu Processes

The **Processes** menu provides functions for automatic calculations and batch processing.

12.1 Batch processing

Menu:	Processes → Batch processing
Precondition:	Loaded project

The function **Batch processing** opens a dialog in which the sequence of successive calculation functions can be set. It is up to the user, to define a correct and functional list of steps.

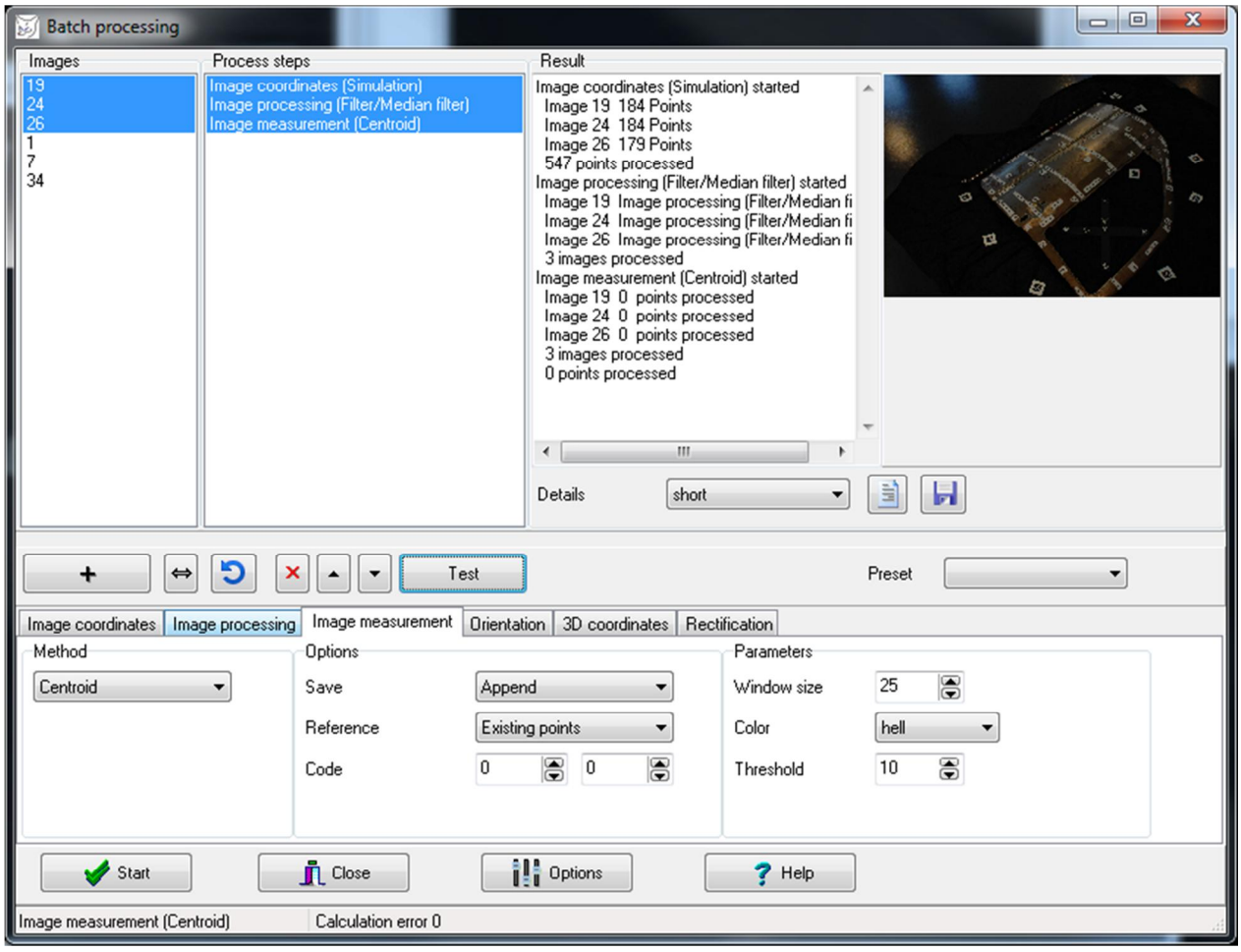


Fig. 142: Batch processing

In the above example, 1) simulated image coordinates are calculated from existing object coordinates, 2) images are smoothed with a Median filter, and 3) the targets at the calculated image coordinates are measured by a centroid operator.

The list of all image objects appears under Images. The images selected here are subsequently processed with the selected function.

The sequentially processed functions are listed under Process steps. With the button + the function displayed in the bottom panel is added to the process list together with its associated settings, or replaced with the button ⇔. Alternatively the *Method* box can be copied by dragging and dropping with the mouse into the list of process steps. With x the selected list items will be deleted. The order of functions can be changed using the arrow keys. The button  reassigns the selected images to the currently selected functions.

Under Result text output of each calculation step is displayed. The level of output detail can be set under *Details*. The currently selected image or any new images will be displayed in the right image window.

The button Test executes the currently selected function without changing the input data. Since no new objects are created in this mode, consecutive functions may not be executed under certain circumstances.

Under *Preset*, the steps displayed in the process list can be saved and reloaded by selection in the drop-down list. These so-called presets are stored in text files with the extension *.ppp. Image assignments to the functions are not stored in the preset. They must be reassigned via the button  .

The button Start executes the process list. Under Output log outputs appear as defined under *Details*. With the button  the log can be saved in an external text file. The button  displays the most recently written log of a single function.

The button Options opens the area Options associated with the selected function page.

With Close the dialog is closed.

12.1.1 Image coordinates

Under **Image coordinates** calculation functions for generating new image coordinates are offered. Under Method, the implemented functions can be selected:

Simulation	Calculation of simulated image coordinates from object coordinates of the selected input object under consideration of distortion and image format. Settings: *Object:* selection of the object with stored object points.

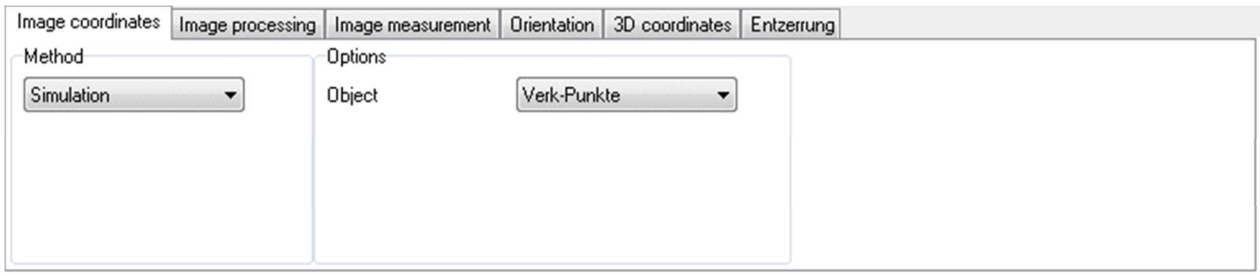


Fig. 143: Generation of image coordinates

12.1.2 Image processing

Under **Image processing** methods for image processing are available. They mostly correspond to the methods and functions available under **Images/Image processing** with their described Options. The results of image processing steps are stored in the image sequence associated with the image and can be displayed and managed under **Images/Properties/Image sequence**.

Under Method the following groups of image processing methods are offered. To each selected method a variety of *Functions* can be selected. To each function various Options can be defined. If *Replace* is selected the original image bitmap is replaced by the final image resulting from a chain of image processing functions.

Contrast	Image processing methods with lookup tables, which map the input color values to new output color values, e.g. for contrast change, reduction of grey levels, gamma correction, etc.
Filter	Image processing methods for filtering of the image, e.g. smoothing, sharpening, edge extraction, etc.
Light fall-off	Automatic correction of optical light fall-off.

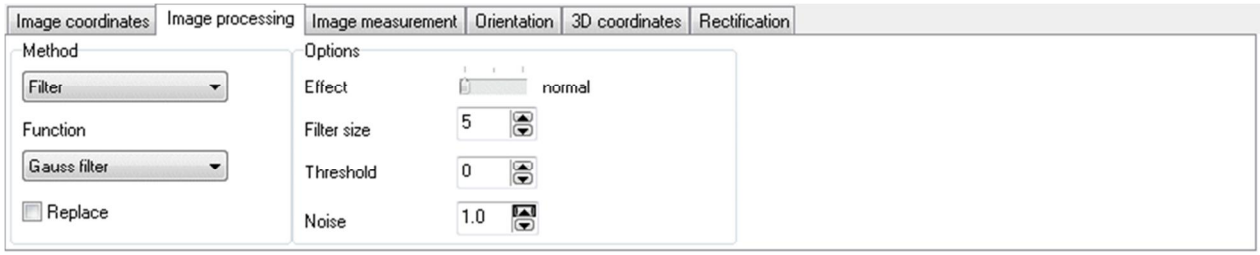


Fig. 144: Methods for image processing

12.1.3 Image point measurement

Under **Image point measurement** several methods for automatic measurement of image points are implemented. They correspond to the methods available under **Edit/Options/Image measurement/Point measurement** (manual measurement is not possible in the batch process). The parameters of individual measurements must be defined under Options for point of measurement. The point measurements are performed at the image coordinates saved to the image. The available Options have the following meaning:

Save:	Selection of storage mode for newly measured image coordinates: *Append*: measured image coordinates are appended to existing points. There

may be duplicate point numbers.

Overwrite: measured image coordinates are stored whereby existing points with the same number will be replaced.

File: Output of the image coordinates to a text file.

Reference: Control of image coordinates used for measurement:

Existing coordinates: initially existing coordinates will be used as starting values for all consecutive image measuring methods;

Current coordinates: the coordinates resulting from the previous method are taken as starting values for the next image measuring method;

Only with code: only image coordinates are used for measurement whose point code corresponds to the value in the right field.

Code: Point code to be used when the point is saved (left panel).

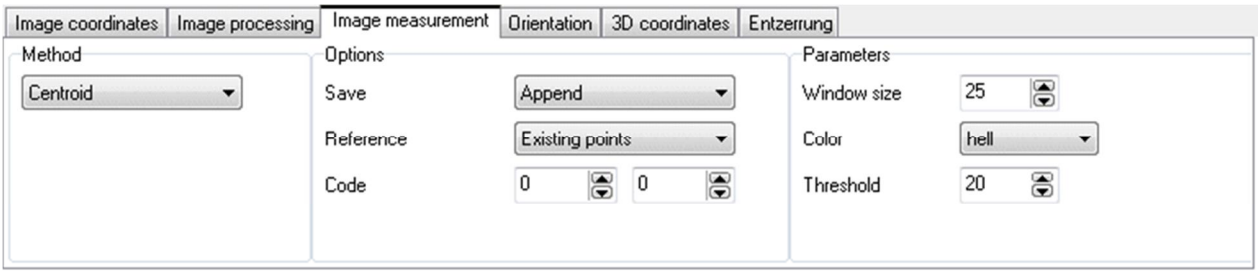


Fig. 145: Methods for measuring image points

12.1.4 Orientation

Under **Orientation**, the following methods for orientation of images are implemented:

Resection Calculation of the external orientation of the selected images by space resection with the following parameters:

Control points: selection of the object with stored control points (min. 3)

Initial values: selection of the method for calculating initial values

Calibration: optional calibration of the camera (*single image* = each image separately, *mean values* = calibration by averaging all participating images)

Direct linear transform Calculation of the external orientation of selected images by a DLT with the following parameters:

Control points: Selection of the object with stored control points (min. 6)

Bundle adjustment not yet implemented.

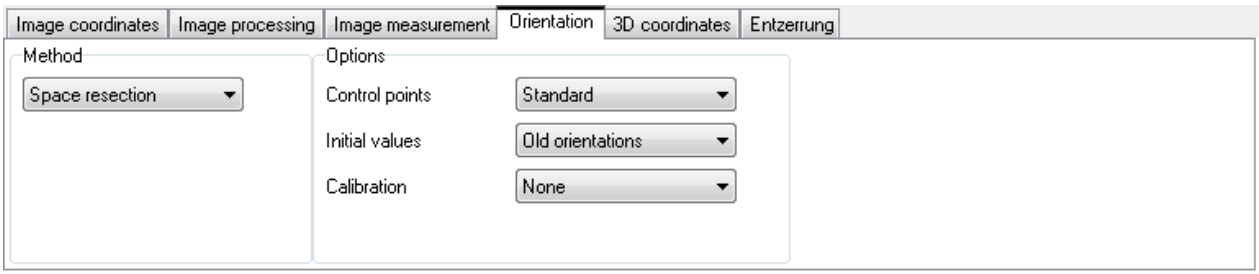


Fig. 146: Methods for image orientation

12.1.5 3D coordinates

Under **3D coordinates**, functions for calculation of 3D coordinates are available. Under *Target object* the object for the newly computed points is selected. By entering a name and the switch a new object can be created. The following methods for the calculation of 3D coordinates are implemented:

Forward intersection — Calculation of the 3D coordinates with the stored image coordinates of selected images

Monoplotting DTM — Calculation of the 3D coordinates with the stored image coordinates of a selected image with the following parameters:
Point cloud/DTM: selection of an object with a surface model for the intersection with the image rays.

Projective transformation — Transformation of the stored image coordinates of selected images into 3D coordinates by the parameters of plane projective transformation that are assigned to the image

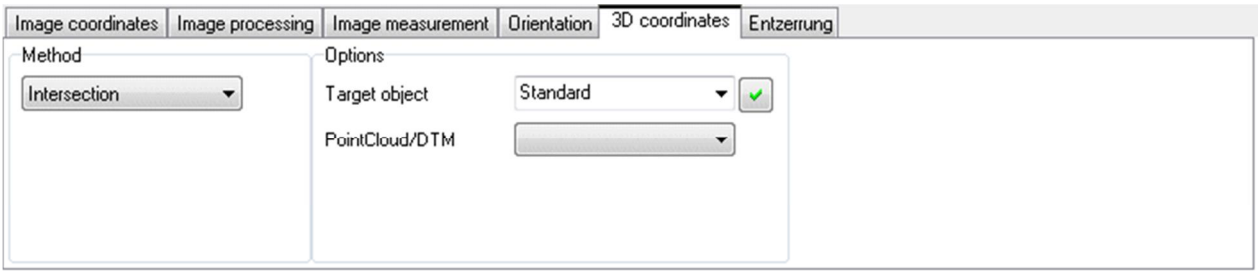


Fig. 147: Methods for calculation of 3D coordinates

12.1.6 Rectification

Under **Rectification**, the following Methods for the plane rectification of images are implemented:

Projective — Plane projective transformation with the 8 parameters given under *Parameters*. These parameters are taken from the previously rectified input image or they can be entered manually.

Affine — Affine transformation with the 6 parameters given under *Parameters*.

Polynomial — Polynomial transformation with the n parameters given under *Parameters* whereby the number of parameters depends on the selected polynomial degree.

Helmert — Helmert transformation with the 6 parameters given under *Parameters*.

The option *All images* uses the currently displayed transformation parameters to rectify all selected images. Otherwise, each image is rectified with the parameters that are associated with the image (see **Rectification/Image rectification**). The option *Manually* allows to enter arbitrary parameter values.

Under Dimensions the area and resolution in object space for the result image will be defined.

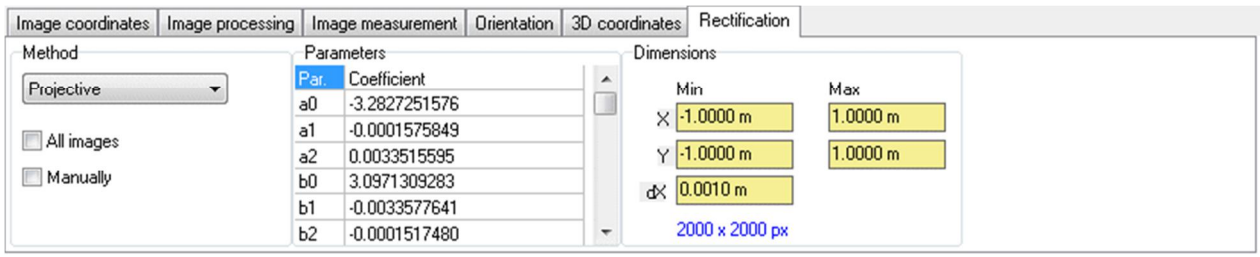


Fig. 148: Methods for image rectifications

13 Menu Windows

The **Windows** menu provides functions to display the image window.

13.1 Mouse coordinates

Menu:	Windows → Mouse coordinates
Button:	

The function **Mouse coordinates** shows a docking window where the pixel and image coordinates of the mouse position in the current image window are displayed.

The option *continuously* enables the continuous updating of the displayed coordinates while the mouse is moving. If the option is disabled, the display will be renewed only after the next mouse click. The *Font size* of the display can be changed with the slider. The cursor in the image window can be changed by clicking on the test image under *Cursor*.

Displayed measured values:

Pixel coordinates: Pixel coordinates *u,v* of the current mouse position. The origin is in the upper left corner of the image. At zoom levels over 100% the pixel position can have non-integer values.

Image coordinates: Image coordinates *x'*,*y'* of the current mouse position. The origin is defined by the transformation type between pixel and image coordinates. In most cases, it is located in the center of the image and the coordinates of the image have the unit mm. The sizes *dx'*,*dy'* denote the distortion correction at the current position. The values *xc'*,*yc'* are the corrected, hence distortion-free image coordinates. The angle τ describes the corresponding angle resulting from image position and principal distance (focal length). The angle α describes the corresponding angle resulting from image position after applying distortion.

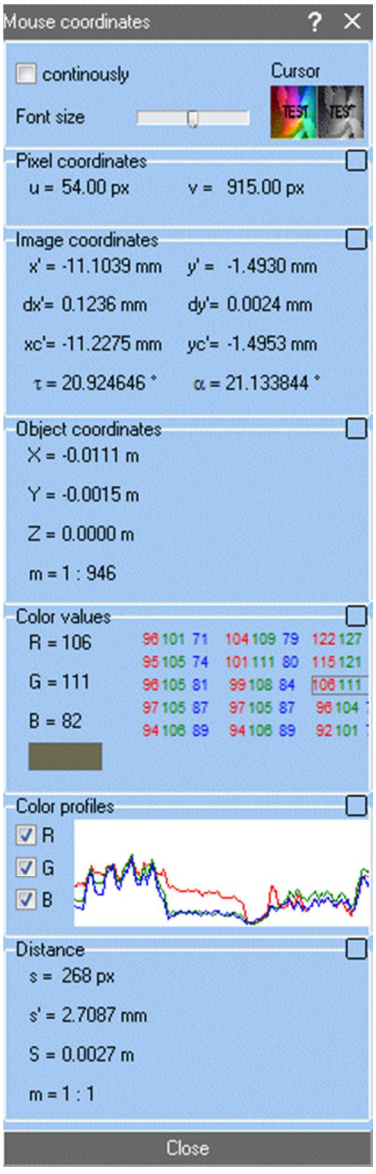


Fig. 149: Window to display the coordinates of the mouse

Object coordinates: Object coordinates *X*,*Y*,*Z* at the current mouse position. Object coordinates can be calculated for a single image, if a numerical rectification is been carried out beforehand, i.e., the parameters of a plane projective transformation have been calculated and assigned to the image. The specified scale *m* shows the current image scale, calculated from the object distance between projection center and object point divided by the corresponding distance in image space.

Color values: Color or gray values at the current mouse position. In addition, the color values of a 5 x 5 pixel window around the current mouse position are displayed.

Color profiles: For activated line mode of the image cursor the color profile along the cursor line is plotted. Starting point of the color profile is the point clicked on in the image. If the Diagram window is opened at the same time, the color values are displayed there in a table and a chart.

Distance: Distance of the current mouse position to the last clicked mouse position in pixel-, image- and object coordinates. The specified scale *m* displays the current image scale, calculated from the displayed object distance and the displayed image distance.

13.2 Zoom window

Menu:	Windows → Zoom window
Precondition:	Opened image window

The function **Zoom window** displays a docking window where enlarged image details of the current mouse position of an image window appear. The zoom window will be updated when clicking into the current image window, with Shift and mouse moving over the image.

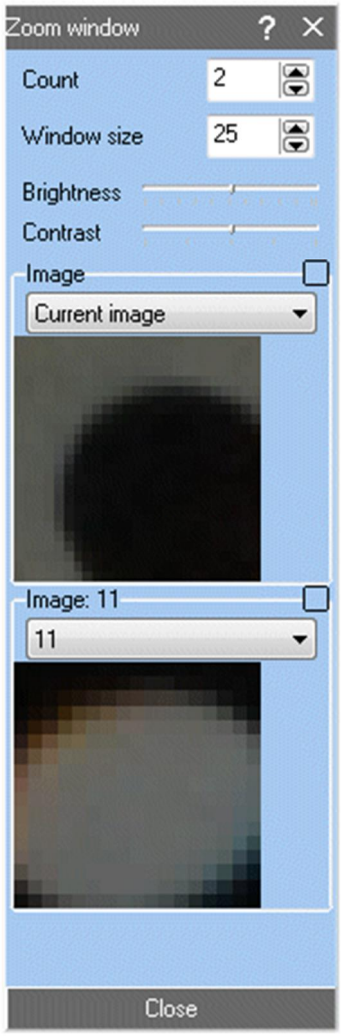


Fig. 150: Window to display an enlarged image details

Settings:

Count: Number of zoom windows to display (0-8).

Window size: Image patch size in pixels which shall be displayed in enlarged mode (1-255). With an input of 1 only a single pixel of the mouse position in the original image is shown, with larger values a correspondingly larger patch is displayed.

Brightness: Changes the brightness of all zoom windows.

Contrast: Changes the contrast of all zoom windows.

Zoom window:

For each zoom window it can be selected which image shall be displayed.

Current image: When clicking in the original image, the enlarged patch of the currently clicked image is shown.

Image number: By choosing a different image number, the enlarged image is updated only after clicking into the image window corresponding to the image number.

13.3 Image properties

Menu	Windows → Image properties
Precondition:	Existing image

The function of **Image properties** displays a docking window for the display of important parameters of the current image. The window is updated when the current image is changed. The docking window can be opened permanently, however, some measuring and calculation functions lock the window to avoid data conflicts.

Under *Image* of the current image number will be shown below. The image can be changed by selecting in the list.

Bitmap:

File: File name of the bitmap associated with the image (without directory)

Columns: Number of columns of the image (width in pixels)

Rows: Number of rows of the image (height in pixels)

Color: Color mode of the image (8 bit grey values, 8 bit color or 24-bit RGB color)

Interior orientation:

Camera: Name of the camera associated with the image

c Principal distance

Additional parameters of the interior orientation appear when the field is enlarged.

Exterior orientation:

Xo, Yo, Zo: Translation parameters of the current image

ω, φ, κ: Rotation angles of the current image

Image coordinates:

Display the image coordinates saved to the image. Click on an item in the list shows the corresponding position in the image window.

Histogram:

Presentation of histograms of the image(s) or selected areas-of-interest in all color channels, as well as output of the respective mean values and standard deviations. If changes are made with Contrast sliders, here the calculated look-up tables are drawn in addition.

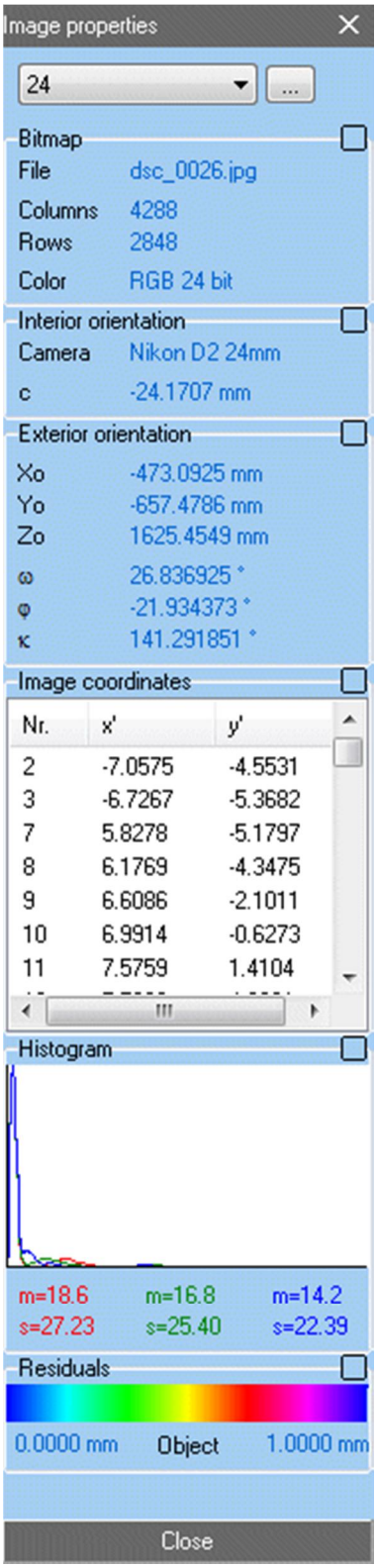


Fig. 151: Window for image properties

Residuals:

Representation of the currently selected color scale and the minimum and maximum limits for the display of residuals in the image. By clicking on *Object* the limits on image residuals or deformations be toggled

13.4 Object properties

Menu	Windows → Object properties
Precondition:	Existing object

The function of **Object properties** displays a docking window where the display parameters of the current object can be manipulated. The window is updated when the current object is changed. Modified parameters are immediately applied to the visualisation of the object.

Objects optionally consist of object points with 3D coordinates, polygons, a point cloud and a triangle mesh. Each of these elements has individual display parameters that are defined under **Objects/Object properties**. The higher-level display of the elements and the associated default settings are defined under **Edit/Options/Graphics**.

The desired object is selected in the upper list. Below this is the selection of the object component whose parameters are to be changed. Changed graphic settings are immediately saved for the current object.

Under Properties the number of associated elements (e.g. number of points or triangles) as well as the date and time of creation or last modification are displayed.

Points:

Display:	Display of object points
Pt.No.:	Display of point number
Symbol:	Symbol type
Size	Symbol size in pixels
Color:	Color of point symbol

Lines:

Display:	Display of lines
Style	Line style
Pattern	Fill pattern

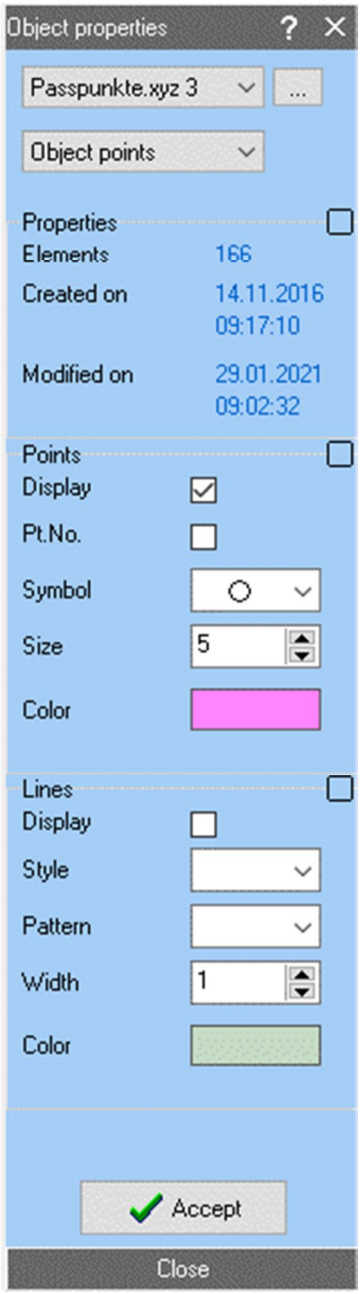


Fig. 152: Window for object properties

Width Line width in pixels

Color: Line color

With Accept the current settings are stored as default values for graphic display as they are also defined under **Edit/Options/Graphics**.

13.5 Point coordinates

Menu:	Windows → Point coordinates
Button:	

The function of **Point coordinates** shows a docking window at the bottom of the screen where either image or object coordinates can be displayed and edited. The selection of image or object coordinates is done through the settings in the Point selection area.

Under Display it is defined whether only the current image or object element (e.g. the current image) or *all elements* (e.g. all images) are selected to list the associated points. If a point is clicked in the table, this point is displayed either in the *current image*, in *all image windows*, or not shown.

Fig. 153: Window for listing image points

If image points are listed, the corresponding point number, image number, pixel coordinates (u, v), image coordinates (x', y'), standard deviations or residuals (sx', sy') as well as the point code are displayed.

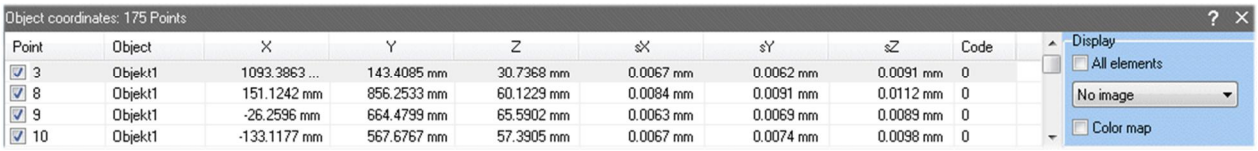


Fig. 154: Window for listing object points

If object points are shown, the corresponding point number, object name, 3D coordinates (X, Y, Z), standard deviations or residuals (sX, sY, sZ) and the point code are listed.

Through the popup menu functions for editing the points are available:

Edit Calling an edit window for editing the point coordinates

Delete Deletes all selected points after confirmation

Select all Selects all points

Toggle selection	Inverts the point selection
Select points	Opens a dialog for the individual selection of points (see **Objects/Object properties/Object coordinates**)
Copy table	Copies the selection into the Windows clipboard

13.6 Graphic window

Menu:	Window → Graphic window
Preconditions:	Existing image

The function **Graphic window** shows a docking window where graphics to the image point distribution, as well as a 3D viewer for the object space can be displayed. The graphics are updated online, hence changes of parameters or image and object selections are transferred directly into the graphics.

Under Image the image point distribution of the selected images will be shown. The image selection is made via the corresponding popup menu:

Current image	Displays the image coordinates for the currently selected image
All image windows	Displays the image coordinates for all open image windows
All images	Displays the image coordinates for all images
No image	Displays no image coordinates
Measured points	Displays the measured image coordinates
Reprojected points	Displays the image coordinates of reprojected object coordinates of the current object

An interactive 3D viewer appears under Object space with the same functionality as the standard 3D viewer. Here a popup menu is available where the currently displayed item can be set.

Fit	Displays the complete object
Origin	Displays the origin of the coordinate system in der center of the view
Reset	Resets the viewer to the default values
Object points	Displays object points
Polygons	Displays polygons
Point clouds	Displays point clouds
Triangles	Displays triangles
Cameras	Displays camera positions
Image rays	Displays image rays between camera positions and object points
Options	Opens the graphics settings under **Edit/Options/Visualization/3D graphics**

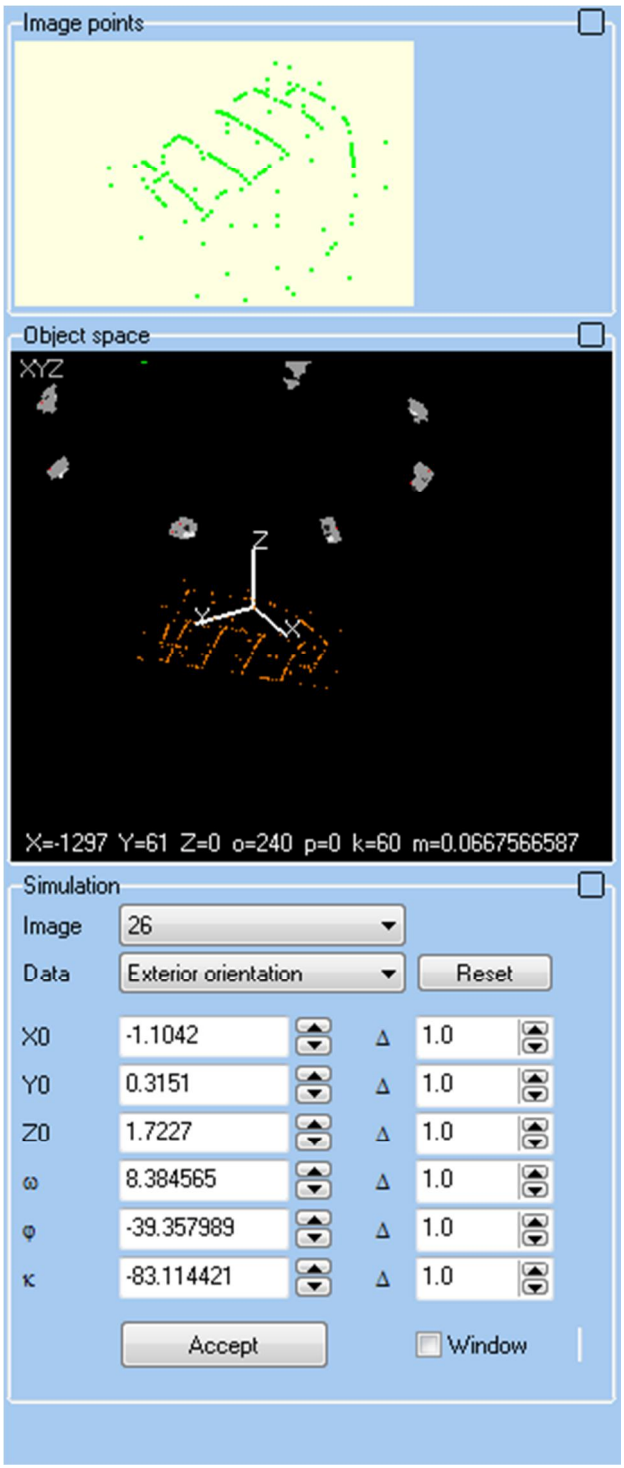


Fig. 155: Window for displaying online 3D graphics

Under Simulation, the *Data* of interior or exterior orientation of an image selected under *Image* can be changed manually. The effect of data changing to the image coordinates and camera positions is visualized immediately in the graphics. If the external 3D-viewer under **Graphics/3D viewer** is visible, the changes will be synchronized there as well. Any change of the input fields leads to a change in the data saved to the image. The values set under Δ are used as the increment for the rocker switches in addition to the data fields. If the options *Image window* is enabled the modifications will have an effect directly in the corresponding image window, i.e. superimposed object information will appear in positions in the associated image.

Under *Data* the following selection can be made:

Interior orientation	The parameters of interior orientation are displayed: principal distance, principal point, two parameters of radial distortion (A1, A2 resp. K1, K2).
Exterior orientation	The parameters of exterior orientation of the current image are displayed
Object point	The 3D coordinates of a point are displayed. For the visualisation the point appears in the style that is defined under **Edit/Options/General/Cursor** > *Stereo mark*.

The original data will be restored if the graphics window is closed or if the button Reset is pressed. With Accept the interactively modified data will be finally assigned to the current image, i.e. the original data cannot be recovered.

13.7 Overview images

Menu:	Windows → Overview images
Button:	

The function **Overview images** opens an overlaid window which is always in the foreground of the desktop. It contains overview images of all image windows.

By clicking into an overview image the corresponding image window is displayed. By holding down the mouse button, the image window can be positioned by movement in the overview image.

In the popup menu, the following functions are available:

Update	The images are rebuilt whereby the size of the overview images adapts to the width of the window.
Sort	The images are sorted by image number.
Close	The overview window is closed but can be reloaded at any time.

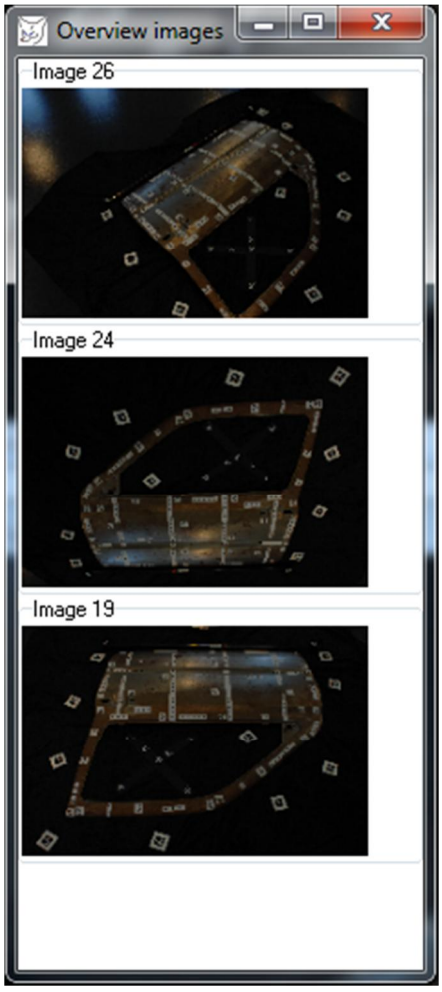


Fig. 156: Window for displaying

overview images

13.8 Diagram window

Menu:	Windows → Diagram window

The function **Diagram window** opens an overlaid window which is always in the foreground of the desktop. It consists of a table and a chart that represents the selected columns in the table as a curve.

The following functions in PhoX provide data for this window:

Measure color profiles — If the Mouse coordinate window is opened and Line cursor is enabled, the color values along the drawn line are transferred into the table.

Distortion curves — The data of the radial-symmetric distortion of the Distortion curve is transferred into the table.

Image histogram — If the docking window Image properties is opened, the data of the displayed histogram is transferred to the table.

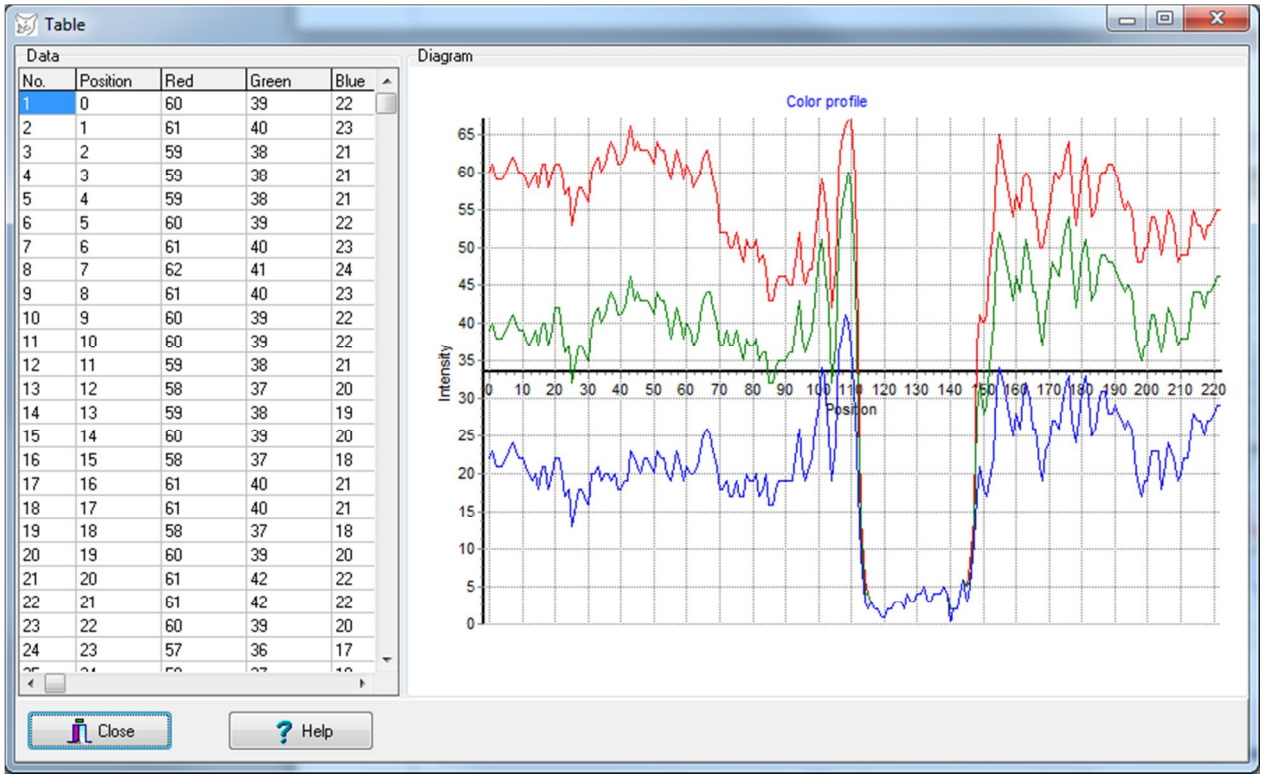


Fig. 157: Diagram window

Under Data a table is presented whose values have been generated by one of the above mentioned parent function, e.g. when measuring color profiles in image windows. A selected column can be assigned to the X-axis of the chart, additional columns show the dependent Y-values. Each Y column appears in the chart as a user-defined curve. Any number of Y columns can be defined. At the end of the table, the corresponding minimum

and maximum values, the mean and the standard deviation are displayed to each column. The table cannot be edited.

By clicking on the column headings, a dialog is opened in which the assigned X or Y values, as well as the color of the graph curve can be defined. The symbol [ ] cancels the assignment. Click on the color box opens a color selection dialog.

Under Diagram, the chart will be shown. It provides the following mouse features:

Draw rectangle	By dragging a rectangle from top left to bottom right will show the diagram of the selected data range. Dragging the rectangle in the opposite direction resets the diagram to the original view.
Right mouse button	The range of values on the axis moves by dragging with the right mouse button.
Click axis	Opens a dialog for specifying axis settings
Click curve	Opens a dialog for defining the curve settings
Double-click	Opens a dialog to define general Diagram properties

The associated popup menu provides the following functions:

Copy	Either copies the chart as a bitmap or the table in Excel format to the Windows clipboard, from where it can be inserted directly into Excel
Export	Stores the table data to a text file (separated by semicolons)
Properties	Opens the dialog for setting of Diagram properties

13.9 Residuals

Menu:	Windows → Residuals

The function **Residuals** opens a docking window in the bottom part of the screen where the display of residuals (e.g. error ellipses) can be controlled dynamically.

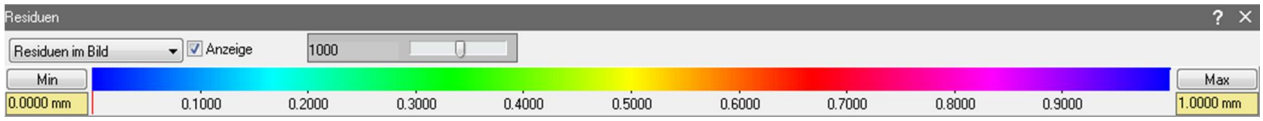


Abb. 158: Window for control of residual display

With the left combo box the type of residuals is selected:

Image residuals	Error vectors or confidence ellipses of image coordinates
Object residuals	Error vectors or confidence ellipses of object coordinates
Deformations	Deformation vectors

The option *Display* switches the output of residuals on or off. The slider resp. the left edit field controls the amplification factor for the residuals. Residuals will be plotter immediately, i.e. slight delay may happen. The buttons Min and Max set the bottom edit fields to the minimal and maximal values computed from all image or object points. The kind of residual display is defined under **Edit/Options/General/Display**.

13.10 Button toolbar

Menu:	Windows → Button toolbar

The function **Button toolbar** turns the custom toolbar on or off. The toolbar contains user-selectable buttons, each associated with one of the existing menu functions. The toolbar is configured under **Edit/Options/General/Menu**. Preconfigured buttons can be read from file or are optionally included in predefined exercises and assistants.

The popup menu of the toolbar has the following functions:

Close Closes the toolbar

Load Loads a toolbar from a text file. The structure of the text file is as follows:

```
# PhoX Buttons
#
Exercise=Relative orientation
  Buttons=5
    Images [Images/Load image]
    Cameras [Cameras/Camera list]
    Interior orientation [Measure/Interior orientation]
    Relative orientation [Orientation/Relative orientation]
    Save project [Project/Save project as …]
#
Exercise=Favorites
  Buttons=3
    Images [Images/Load image]
    Cameras [Cameras/Camera list]
    3D [Graphics/3D viewer]
```

When loading the file, the user is asked for the desired item (`Exercise`) which respective buttons (`Buttons`) shall be loaded. Each button consists of a caption (e.g. `Images`) and the path to the desired menu item (e.g. `[Images/Load image]`). The menu path must match exactly the spelling in the PhoX menu.

Edit Call to the function **Edit/Options/General/Menu**

13.11 Tile horizontal

Menu:	Windows → Tile horizontal

The function **Tile horizontal** positions all image windows side by side on the screen.

13.12 Tile vertical

Menu:	Windows → Tile vertical

The function **Tile vertical** positions all image windows on the screen one below the other.

13.13 Cascade

Menu:	Windows → Cascade

The function **Cascade** positions all image windows with a small offset starting at the top left corner of the screen.

13.14 Stack

Menu:	Windows → Stack

The function **Stack** positioned all image windows directly one above the other in the upper left corner of the main window. All image window are displayed with the zoom factor of the first image in the image list. This function is useful if images of a sequence shall be displayed as a film, e.g. with the buttons  and  of the top toolbar.

13.15 Arrange

Menu:	Windows → Arrange
Precondition:	Opened image window(s)

The function **Arrange** positions all image windows all over the screen.

13.16 Reduce all

Menu:	Windows → Reduce all

The function **Reduce all** minimizes all image windows and generates appropriate icons at the bottom of the screen. The windows can be enlarged again **Enlarge all**.

13.17 Enlarge all

Menu:	Windows → Enlarge all

The function **Enlarge all** restores the display status of all image windows if these have been minimized before with **Reduce all**.

13.18 Close all

Menu:	Windows → Close all
Precondition:	Opened image window(s)

The function **Close all** close all image windows.

14 Menu Help

The **Help** menu provides functions for problem solving and program documentation.

14.1 Help window

Menu:	Help → Help window

Displays the quick help window (Quick Help) in the lower area of the main window screen where context-sensitive help text shown. The help texts are stored in the file PhoxQuickHelp.cc.rtf, and can be edited or expanded by the user.

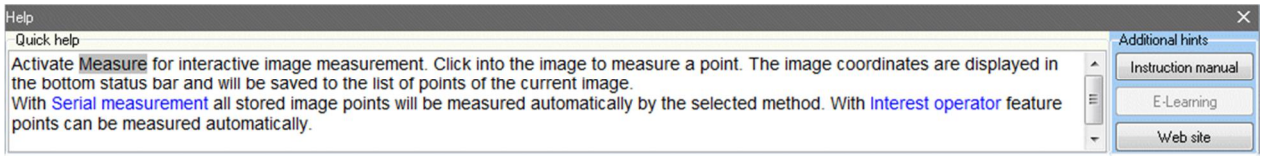


Fig. 159: The quick help window

The button Instruction manual opens the PDF file with this user guide. The button E-Learning opens a PDF file associated to the current menu function by the user (e.g. teacher), see chapter Teaching materials. The button Web page opens the PhoX website in the current internet browser.

14.2 Instruction manual

Menu:	Help → Instruction manual

The function **Instruction manual** opens the PhoX user guide (this document). This is a PDF file that is viewed using a PDF reader. PhoX searches automatically the program registered to open PDF files (usually Acrobat Reader). If no program is found or the help file is not displayed, a corresponding program can be defined manually under **Edit/Options/General/Program**.

Within the help documentation, hyperlinks allow for cross-references to other chapters.

14.3 Homepage

Menu:	Help → Homepage

The function **Homepage** opens the PhoX homepage with the implemented internet browser, which represents current information about the program. If a browser is not found or the internet site is not displayed, a corresponding program can be defined manually under **Edit/Options/General/Program**.

14.4 Error messages

Menu:	Help → Error messages

The function **Error messages** opens the section in this manual explaining various Error messages.

If severe program problems happen it is recommended to create a Project archive and send all files to the program suppliers or the supporting teachers.

14.5 Assistant

Menu:	Help → Assistant
Precondition:	Closed project

The function **Assistant** opens a docking window where prepared program sequences (tasks) for typical photogrammetric workflows can be called. The contents are stored in the file PhoxAssistant.cc.txt, which may consist of an arbitrary number of tasks, has the following structure:

```
#
# PhoX Project assistant
#
MainDirectory=X:\Teachers\Luhmann\Photogrammetry\
Exercise=Image measurement
  Directory=[ProgramDir]Exercises
  Sheet=
  Steps=4
    Create and store camera [Cameras/Camer list]
    Load image [Images/Load image]
    Measure image points [Measure/Image coordinates]
    Save project [Project/Save project as …]
#
```

The file contains predefined keywords and related descriptions:

MainDirectory Superior directory which is used with keyword *Directory*

Exercise Name of the assistant

Directory Directory in which PhoX will execute the project. The optional placeholder [ProgramDir] replaces the text by the directory defined under *MainDirectory*.

Sheet Directory path and name of an arbitrary PDF file which optionally can be displayed as assisting teaching material to the actual assistant.

Webpage Link to an arbitrary website

Steps Number of menu calls. The following calls to menu functions consists of a text follows by the exactly spelled menu path.

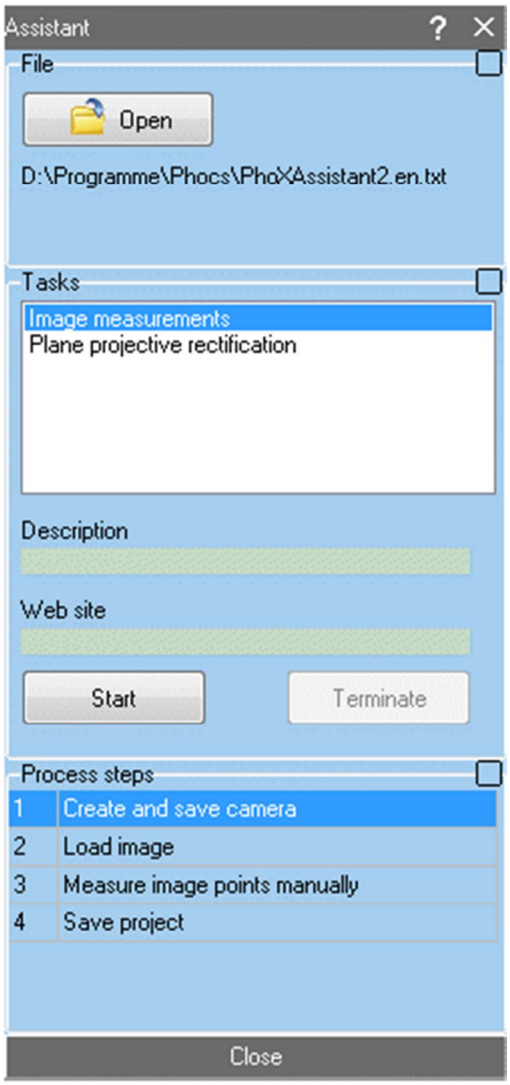


Fig. 160: Docking window of the assistant

Under Tasks, the topics that are stored in the file can be selected. After the selection, the name of the associated PDF file, which contains detailed information about the exercise, appears under *Description*. By clicking on the file name, the installed PDF reader is called to display the file. Under *Website* the link to the associated website can be clicked to open the internet browser.

Start activates the selected task. This automatically creates a new project and the already existing project will be closed. Then, the Process steps can be processed by clicking with the mouse. For this purpose it is advisable to follow the steps in the specified order, since otherwise this can result in inconsistent data or

function calls. Clicking on individual work steps is equal to the call of the corresponding menu, i.e. it can also be worked directly in the program or deviated from the process order. Exit terminates the current task.

The button Close closes the window. It can be called at any time.

14.6 Exercises

Menu:	Help → Exercises
Precondition:	Closed project

The function **Exercises** works like the assistant window. It opens a docking window, where prepared exercises for photogrammetry may be called. The training contents are stored in the file PhoxExercises.cc.txt which has the same structure as the assistant files. Example:

```
#
# PhoX Exercises
#
MainDirectory=X:\Lehrende\Luhmann\Photogrammetrie\Übungsaufgaben
Exercise=Camera parameters and fiducial marks
  Directory=Module 1 Aerial camera
  Sheet=PhoX Module camera parameters and image data.pdf
  Project=
  Webpage=
  Steps=5
    Load image [Images/Load image]
    Create and save camera [Cameras/Camera list]
    Assign camera to image [Images/Image assignments]
    Interior orientation with fiducial marks [Measure/Interior orientation]
    Save project [Project/Save project as ...]
  Buttons=4
    Image [Images/Load image]
    Camera [Cameras/Camera list]
    Interior orientation [Measure/Interior orientation]
    Save project [Project/Save project as ...]
#
Exercise=Digital camera and distortion
  Directory=Module 2 Digital camera
  Sheet=PhoX Module Digital camera and distortion.pdf
  Project=
  Steps=5
    Load image [Images/Load image]
    Create and save camera [Cameras/Camera list]
    Display coordinates [Windows/Mouse coordinates]
    Save project [Project/Save project as ...]
    Analyse distortion [Graphics/Distortion curves]
```

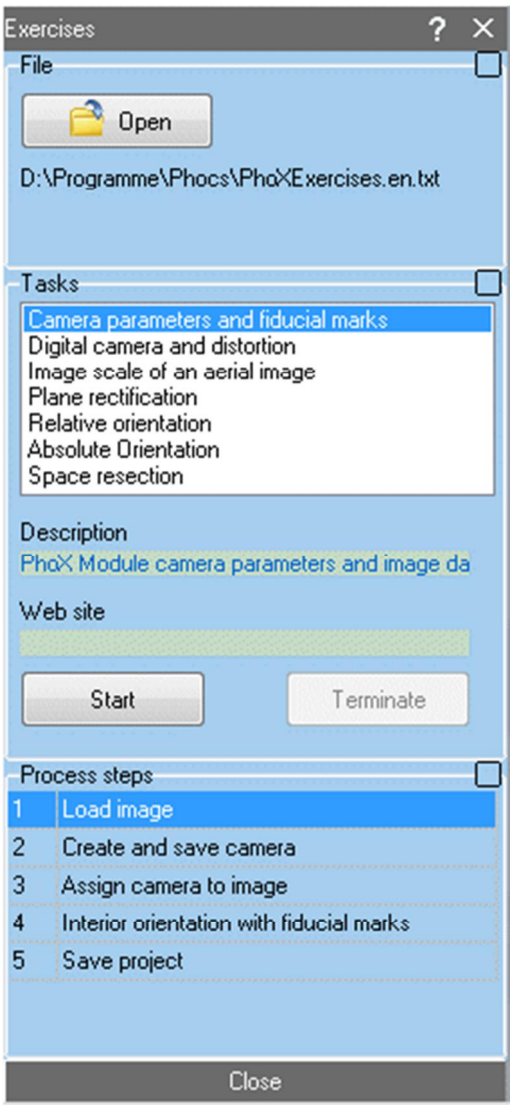


Fig. 161: Docking windows for predefined exercises

Under Tasks, the exercises that are stored in the file can be selected.

Start activates the selected exercise. This automatically creates a new project and the already existing project will be closed. Then, the Process steps can be processed by clicking with the mouse. For this purpose it is advisable to follow the steps in the specified order, since otherwise this can result in inconsistent data or function calls. Clicking on individual work steps is equal to the call of the corresponding menu, i.e. it can also be worked directly in the program or deviated from the process order. Exit terminates the current exercise.

The button Close closes the window. It can be called at any time.

14.7 Registration

Menu:	Help → Registration

The function **Registration** opens a window for entering the user data (only for students). Each user must register or login with last name, first name and student ID number. The data of the last user logged in on the current computer are displayed automatically. The registration window appears automatically when the program starts.

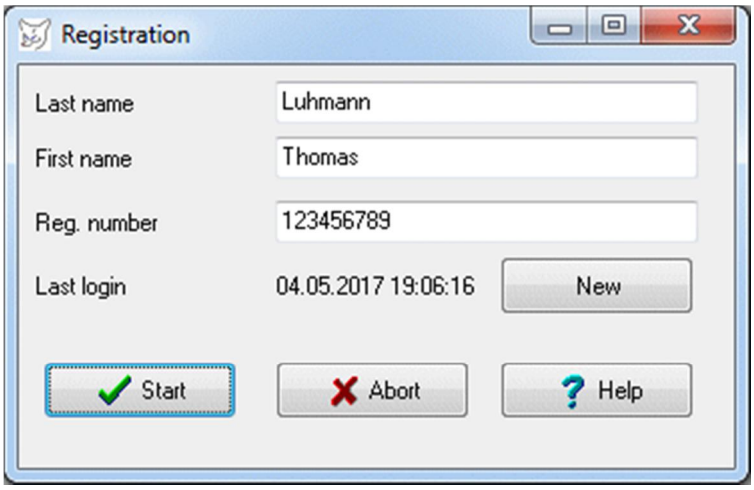


Fig. 162: Login window

The button New clears the displayed information. After pressing Start PhoX is started. Abort closes the window and terminates PhoX.

14.8 About PhoX

Menu:	Help → About PhoX

Displays a window with information about program version, copyright and important information.

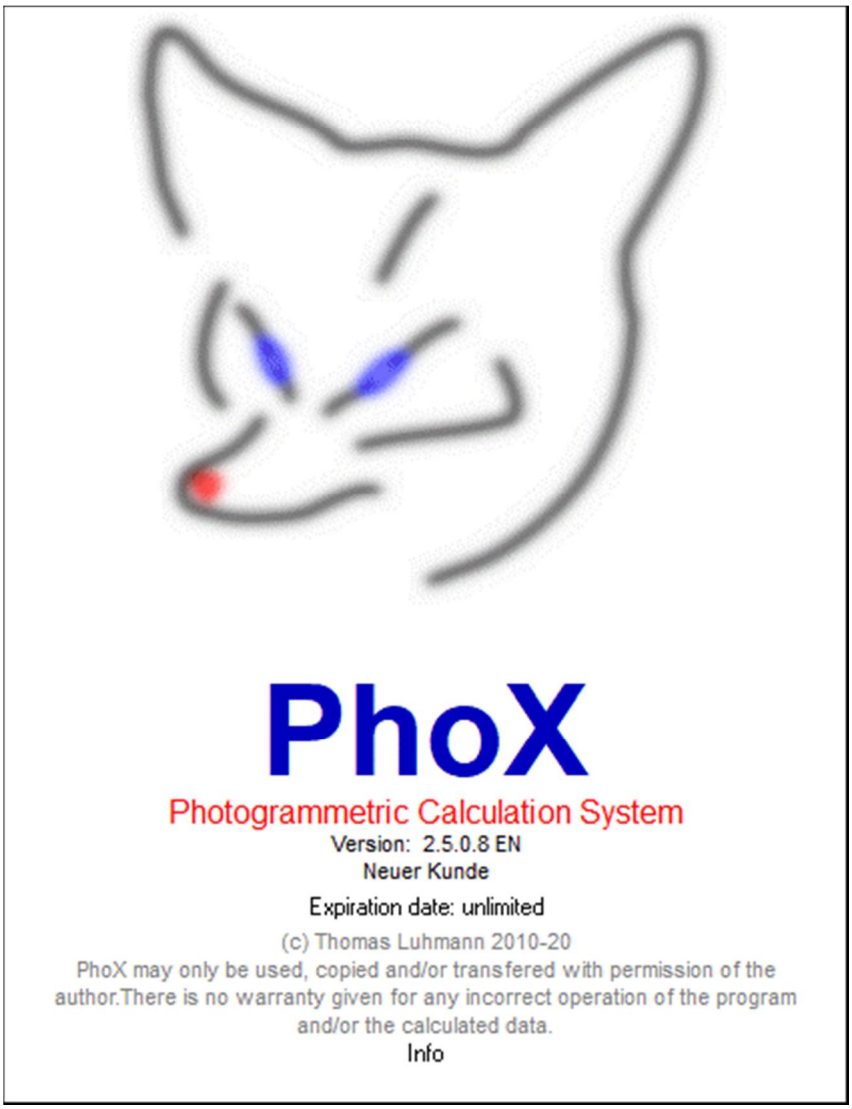


Fig. 163: Info window

Under *Expiration date* the date until which the current program license is valid appears. A click on this field opens the dialog under **Help/Updates**.
A click on *Info* shows a license code. A double click on this code copies the string to the clipboard and also opens the dialog for user information (only in the full version).

14.9 Updates

Menu:	Help → Updates

Displays a window to check for existing newer program versions.

The button Check for newer version will determine whether a newer version of the program is available according to the current program license (student, academic). The student version opens an Explorer window of

the network drive where the new version is saved. In the academic version PhoX tries to establish a connection to the PhoX server (possibly Windows must provide permission for this operation).

With the button Download new version the corresponding ZIP file with a full version of PhoX is downloaded. The file is saved to a user-specified location, but not automatically installed. Clicking on the file name opens the file explorer in the corresponding directory.

With the button Visit PhoX website the default browser opens and loads the PhoX website. From there, new versions can be downloaded if necessary.

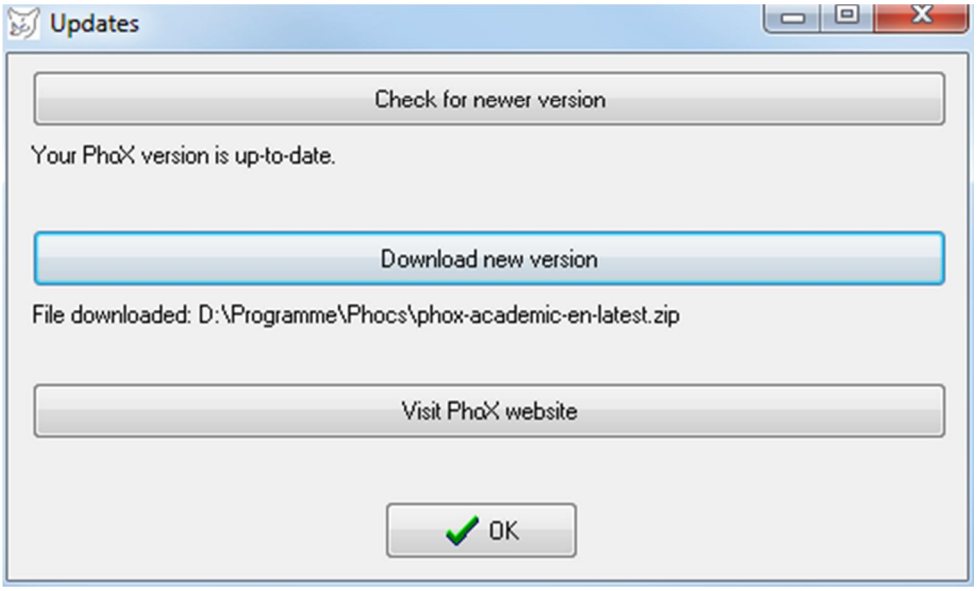


Fig. 164: PhoX updates

15 Trouble shooting

The typical problems, error messages and suggested possible solutions are described in the following section.

15.1 Error messages

PhoX generates different error messages for incorrect operations or calculation problems. Possible reasons and fixes are listed in the following:

Error code	Description
1000	File not loaded The entered file could not be loaded. Check possible problems with access rights (e.g. for server disk space) or if the file has been opened by any other application.
1001	File not found The entered file name could not be found. Check spelling and possible problems with access rights (e.g. for server disk space). Also check if the desired file really exists.
1002	Invalid file name The entered file name does not match the Windows rules for correct file names. Check hard drive name, server name or file name.
1003	File access error The file cannot be accessed due to a problem with access rights. Check if the file is already used by any other program and close it in case. Check your read and write rights.
1004	Invalid file format The file does not consists of correct data or the data is stored in a wrong format (e.g. coordinates, project file etc.). Possible error sources are invalid decimal character (dot or comma), tabs within the text file, empty file or others. Special input formats can be defined in the PhoX program options.
1005	File format is (not yet) supported The format of the image file cannot be loaded by PhoX. Save the file under another format such as JPEG, TIFF or BMP.
1006	Image file not found The entered file name could not be found. Check spelling and possible problems with access rights (e.g. for server disk space). Also check if the desired file really exists.

1007 Error in contour file
The text file with data of measured image contours (edges, lines) does not match the required format.

-1008 Warning: very large image size
The loaded images exceed the limit of 500 MB of RAM so that some function do not work or work only with certain limitations. If images are temporarily not used the associated bitmaps should be removed from the project tree. The image data is not lost and can be reloaded at any time.

2001 Singular equation system
For an adjustment process a singular normal equation matrix exists. Possible reasons can be insufficient distribution of observations (e.g. control points, image points). Check the input observations (measured values) and activate in program options a more detailed output logfile in order to identify the problem.

-2002 Maximum number of iterations exceeded (warning)
The warning will be displayed if an adjustment process does not converge. Check all input data and optionally increase the number of permitted iterations.

2003 Not enough observations or points
The adjustment cannot be started because the number of observations is smaller than the number of unknowns.

2004 Invalid data of interior orientation
The current image has no valid data of interior orientation, e.g. a wrong principal distance (must be negative), a wrong sensor format or an inconsistent camera.

2005 Invalid data of exterior orientation
The current image has no valid data of exterior orientation, e.g. a singular rotation matrix. Check exterior orientation data in image properties.

2006 Function not defined
The selected function is not defined or not yet implemented.

2007 Invalid data of stereo model
The selected stereo model has inconsistent data, e.g. no assigned images or the same image as left or right image.

2008 Invalid data of relative orientation
The selected stereo model has inconsistent data, e.g. identical images left and right or a base length of zero.

2009 Collinearity equations cannot be calculated
The denominator of the collinearity equations is equal to zero. Possible reasons are that object

point and perspective center are identical, or the object point lies in the image plane

2010 Invalid point distribution
The spatial distribution of image or object points is not valid or very weak, e.g. if points lie on a common straight line or if they form are very small area.

2011 No initial values found for space resection
For space resection no starting values could be computed. A typical reason is a bad configuration of image and object points.

2012 No convergence
The adjustment does not converge.

2013 Invalid images for stereo model
The images assigned to a stereo model have inconsistent data

2014 No height model assigned
The calculation of orthophotos or measurements by monoplotting cannot be performed because a digital height or surface model has not been selected.

2015 Monoplotting cannot be performed
The measurement of object points by monoplotting fails because there is no intersection of an image ray with the surface. Possible reasons are erroneous surface models (triangles, DTM), missing orientation data of the image or an image measurement that points to a point outside of the surface model.

2016 Function is not yet implemented
The desired function is not available.

2017 The polynomial degree must be in the range 1 to 5

3001 Error at point measurement
Error for image point measurement. Possible reasons are a too small measurement window, so that a point pattern cannot be covered completely. Other possible reasons are low contrast, blurred images or occlusions that disturb the point pattern.

3002 Points outside window or image
The point to be measured lies outside the measurement window, or outside of the complete image.

3003 Resulting point coordinates outside window or image
The result of a point measurement lies outside the measurement window or the image.

3004 Undefined template
There is no template available for the measurement method Template Matching.

3005 Maximal permitted deviation exceeded
The calculation of a point center has led to a standard deviation that is higher than the permitted limit.

3010 No points above threshold
There are not enough image points with greyvalues above the selected threshold. The threshold can be adapted in the program options.

3020 Measurement method is not defined
The selected function is not defined or not yet implemented.

3030 No edge found
The measurement of lines or contours has failed.

3040 Invalid nodes for contour measurement
The entered nodes for contour measurements are not valid.

3041 Maximum permitted curvature for contours exceeded
The line following process for contour measurement was interrupted since the curvature of the line is too high.

3042 Maximum permitted number of contour points exceeded
The maximum permitted number of contour points has been exceeded and the measurement was terminated.

3043 No edge found for contour measurement
There were no sufficient edge points for contour measurement.

3044 Contour points too narrow
The measured points of a contour are too close to each other.

3050 No target code detected
A coded target could not be detected, e.g. because of missing contrast.

3051 Target code not decoded
The code of a target could not be decoded to a valid point number.

4001 Not enough memory
There is not enough available memory space (RAM).

4002 Invalid input
The entered value was not correct. Check spelling and/or permitted range of values.

4003 Invalid object
The selected object has invalid properties.

5001 Invalid color format of image
The current image consists of an invalid color format that is not supported by PhoX, e.g. 32 bit images. Use another image processing program and save the image with a valid format, e.g. grey level image with 8 bits or true color images with 24 bits.

5002 Invalid filter size
The selected filter size is not supported.

5003 Invalid image address
There is no access to image data in memory.

5004 Invalid image size
The size of the image is not valid. The minimum size of rows or columns is 1, the maximum size is 10000.

5005 Invalid template size
The loaded template image has an invalid size. Template images but have at least 3x3 up to 255x255 pixels, with odd numbers of rows and columns. Templates may have rectangular shapes (e.g. 7 x 19).

5006 Invalid image window for matching
The reference window and/or the search window for matching and correlation is not valid.

5007 Correlation coefficient is too low
A correlation function has resulted with a correlation coefficient below the minimum threshold which has been defined in **Edit/Options/Image measurement/Correlation**→*Threshold*.

9000 Invalid license file
The license file PhoX.plf is corrupted or consists of invalid characters.

9001 Invalid MAC address
The license for PhoX does not correspond to the existing physical MAC address.

9002 License period expired
The licensed period for using PhoX has expired.

9003 Invalid dongle
The used USB protection device (dongle) is invalid or cannot be detected.

9004 Invalid license options
The executed PhoX version is not compatible to the existing license file.

9005 Invalid country settings

9006 Invalid network drive

The network drive encoded in the license file does not exist or cannot be accessed.

9007 Invalid version
The current version of PhoX does not match the licensed version.

9008 No server connection
There is no connection to the PhoX server

9009 Invalid download name
The file requested for download does not exist.

9010 Download error

15.2 Run-time errors

Run-time errors are created by the compiler, e.g. for invalid file access.

1 Invalid function number
2 File not found
3 Path not found
4 Too many open files
5 File access denied
6 Invalid file handle
12 Invalid file access code
15 Invalid drive number
16 Cannot remove current directory
17 Cannot rename across drives
100 Disk read error
101 Disk write error
102 File not assigned
103 File not open
104 File not open for input
105 File not open for output
106 Invalid numeric format
200 Division by zero
201 Range check error
202 Stack overflow error
203 Heap overflow error
204 Invalid pointer operation
205 Floating point overflow
206 Floating point underflow
207 Invalid floating point operation

210	Object not initialized
211	Call to abstract method
212	Stream registration error
213	Collection index out of range
214	Collection overflow error
215	Arithmetic overflow error
216	General protection fault

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