PHIDIAS

Image Orientation

Version 2.85

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1. Introduction

Before photogrammetric object evaluation based on measuring images can begin, the geometrical situation at the time of photography is to be mathematically reconstructed **(image orientation)** . The image orientation is most suitably done by bundle adjustment.

The mathematical model of the photogrammetric mapping is based on the model of central projection. Hereby the coordinates of well-chosen points measured in the image plane are put in direct, functional relation to the corresponding object points. Thus the object point, projection center and image point must ideally lie on a straight line called image ray (co-linearity condition). In reality, the mapping is not that ideal due to physical shortcomings, primarily distortions of the mapping system. However, these can be handled by a due extension of the mapping model.

As a special feature also straight lines can be processed as observations in the image orientation. Therefore corresponding object edges are measured in the images, the end points of the line pieces in the images need not be identical. The mathematical models of the image orientation are accordingly been extended for this special observation type, so that the line observations can be used like point coordinates. The advantage of this extension is effective primarily if in the images not enough discrete points can be localized, but homologous object edges very well.

With the image orientation by bundle adjustment all image ray bundles, which are defined through measurements of image coordinates in each image, are fitted onto the object points under the least possible residual errors. The mathematical tool for this is statistical adjustment. The aim of the adjustment is to derive the most plausible values of the wanted and unknown orientation parameters using the measured observations.

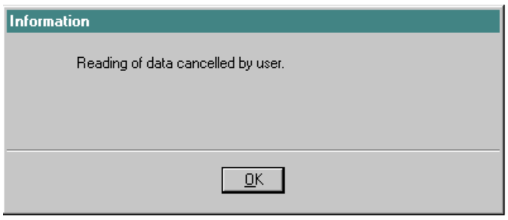
The program MBUN has all necessary modules for the skillful realization of the picture orientation. In the following chapters 2 to 13 the detailed use of this software is described. The explanations are based on a practical numerical example. The main attention hereby is focussed on the practical use of the orientation module. Basic and general aspects of the orientation strategy in MBUN are described in chapter 14, with emphasis preferably on how the single software components are interconnected.

2. General Remarks

The orientation program MBUN is integrated entirely into **MicroStation** and is operated by its graphical user interface. After calling the program all further actions are controlled through a dialog box. Because image orientation is an entirely alpha-numeric process, no further functions of MicroStation are used. So the relatively large dialog box of MBUN remains open during orientation and should be closed only when this process ended.

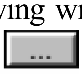
The most important operational tool is the mouse, apart from keyboard inputs into text boxes. Usually the different procedures are controlled and started by mouse cursor and buttons. A double click (e.g. in list boxes) is in most cases equal to pressing the enter key. Generally, even if with some effort, all procedures may be started using the keyboard. Notice that space bar does the same as enter in many cases.

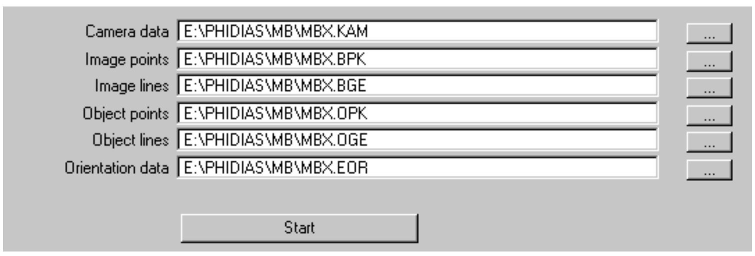
Especially within larger projects (e.g. 50 images and more) procedures like reading or analyzing data could take more time. In every case there should appear screen messages informing about the continuation of the procedure. To cancel such procedure press any key. Then a screen message informs about the cancellation.



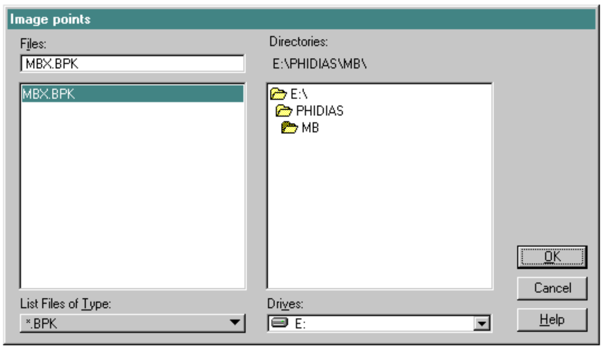
The window confirming the cancellation of a process

2.1 File Name Dialog Box

There are many files engaging in a project while working with PHIDIAS. Every file has an identical name to the project's name but each file has a different extension from the others in conjunction with its functionality. The file names generally are derived automatically from the project name. For instance if a new project named MBX is created, all subordinate files will be designated as MBX with some different extensions, i.e. MBX.KAM, MBX.OPK, MBX.BPK, etc. However independent form the general naming rule discussed above, the user can modify the file names through a list. In the following window by clicking Start button you can change the file names. To get the path of a file click  icon behind the file name.



Example of the display of file name at beginning of a sub-process



Dialog box to modify file names

NOTE: Changing file names is rarely done by experienced users and it is highly recommended that non-experienced users should avoid changing file names.

By clicking  icon another box will open and you can change the directory and the name of a particular file. All the operations are included to the existing files and there is no possibility of creating some new files in this box, so this choice has to be done in the other boxes of the program.

2.2 "Info" Check Box

In most panels and windows of PHIDIAS a check box labeled “Info” is available at the bottom of the window. If you switch it ON by a single left click of the mouse, some excessive information about the basic knowledge of the operation which is going to be done by the software, will appear.

2.3 Example for Demonstration

Together with the image orientation software the example MBX is provided. This example is from architectural photogrammetry.

The example MBX comprises 6 files altogether.

MBX.BPK: The project MBX consists of a total of 10 images which are distinguished with image numbers from 1 to 10. In each image 13 to 21 image points were measured for the orientation.

MBX.BGE: In part of the images there are straight lines given as observations, which can be used for the image orientation. These are administered in a separate file, like common image points. The starting- and the end-points of these lines are recognized as normal image points by the program and saved into the same file.

MBX.KAM: All images were taken by one camera (camera number 10 in the provided default camera list). The precise calibration data of the camera are not known; the focal length of the lens used is about 35 mm.

MBX.EOR: In the file of the orientation data the values for the projection centers (X0, Y0, Z0) and for the camera rotations (ω, φ, κ) are still unknown at first and therefore set to zero. In MBX.EOR is also the assignment of the camera to the respective image defined (see also chapter 13 *Data Formats*).

MBX.OPK: This file contains the control point coordinates. In this example four object points are used (No. 101 to 104).

MBX.OGE: If image straight lines are used in image orientation, the file MBX.OGE is required for object space data. It contains the data of the object straight lines in three-dimensional space.

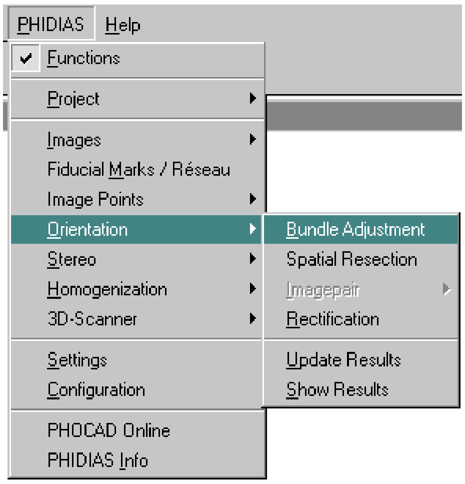
All six files are usually created with a new project and are filled with data in the course of the program. Moreover, these files can be edited with a usual editor program. The records in the files are principally format-free, but notice the statements in chapter 13 *Data Formats*, so that the data can be read correctly.

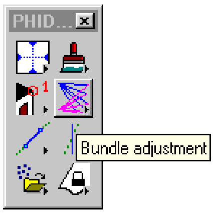
3. The Main Menu

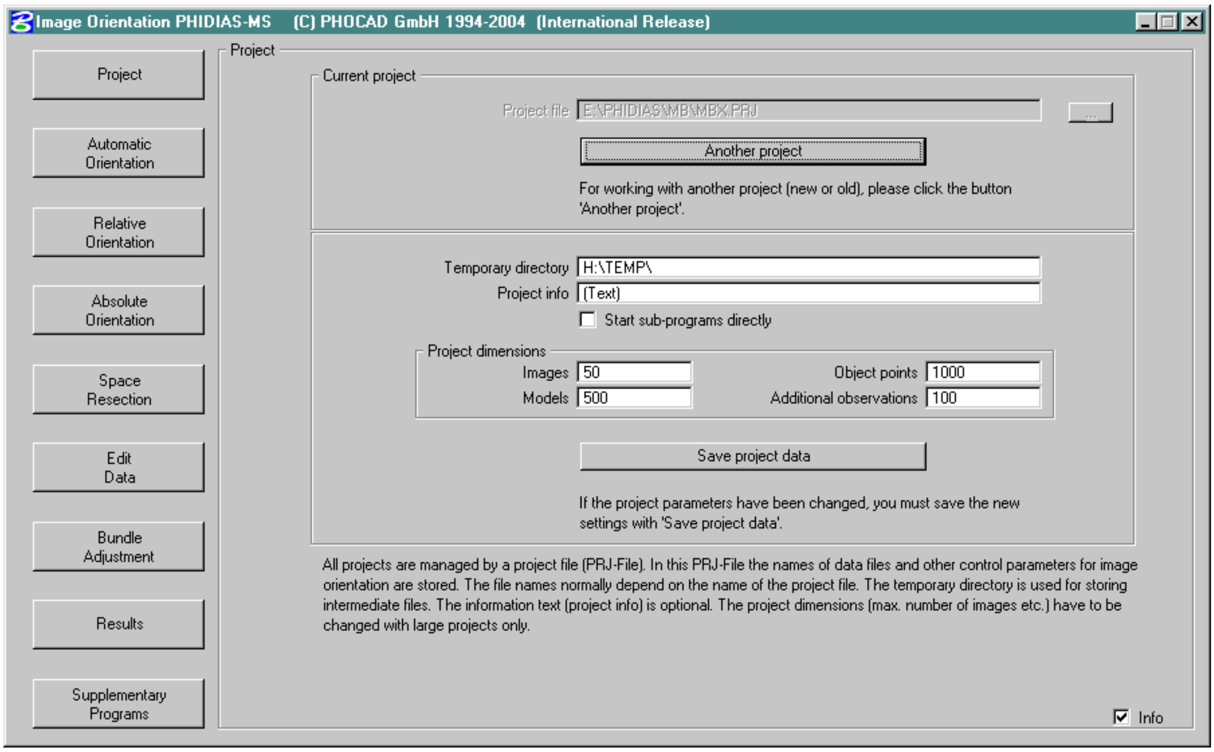
Basic aspects of the image orientation which also refer to the mathematical bases of the photogrammetry are demonstrated in chapter 14 *Basics of Image Orientation*. In the following the basic of bundle adjustment program is explained.

3.1 Starting the Program

After the correct installation the program "Multi-Image Orientation" can be called through the following path: **PHIDIAS | Orientation | Bundle Adjustment**. Alternatively the suitable icon can be also clicked from the main pallet of PHIDIAS.

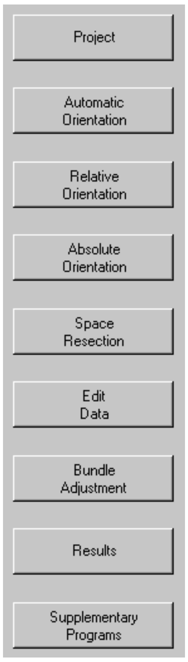






The main window of multi-image orientation

As shown beneath the main pallet of the Image Orientation window contains the following sections:



Project (Project name, Project extent etc.)

Automatic Orientation

Relative Orientation

Absolute Orientation (with several transformation methods)

Space Resection (Orientation of a single image)

Edit Data (Modifying different project files)

Bundle Adjustment

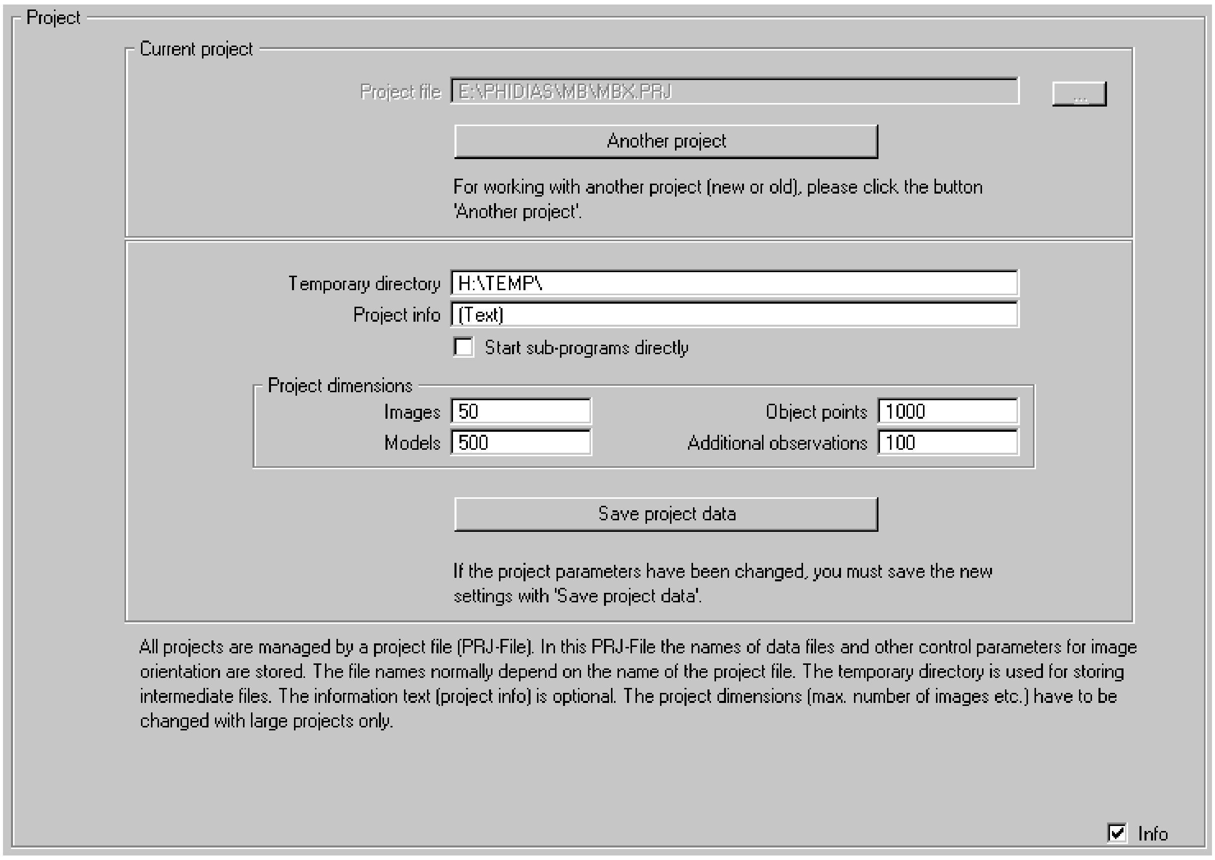
Results

Supplementary Programs

The main pallet of multi-image orientation window

By clicking each of the above mentioned icons the main window changes to an new one. To continue the work flow you should click on the *Start* button after this.

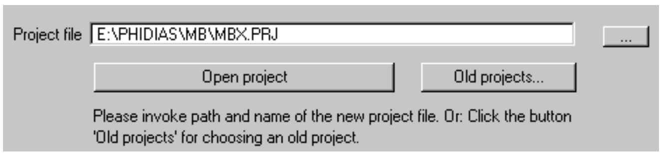
4. Project Management



After clicking the button *Project* the above shown dialog elements appear, which are going to be explained in the following:

Project File: The *Project File* field usually contains the name of the project file with the extension of PRJ and also the path in which the project file has been stored. This path is identical to the one in which the other files like *Object Coordinates* and *Image File* were stored.

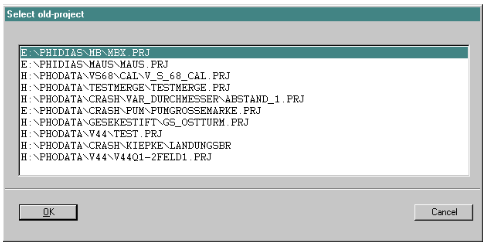
The last project that was loaded before is shown in this field by default. For loading another project to modify click on the key *Another Project* and select your project.



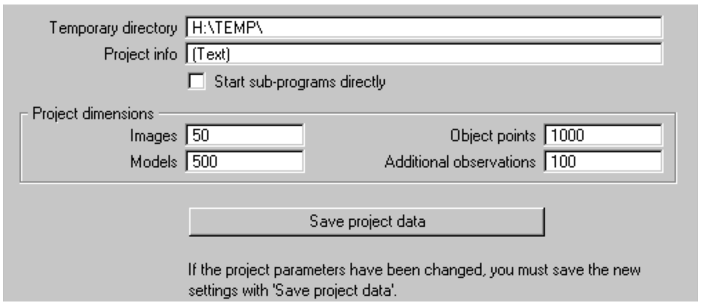
After clicking *Another Project* an already existing or in case an entirely new project may be defined.

By clicking the *Old Project* button a list of existing projects will be loaded or a new project can be created by entering the appropriate name for that. In this case all the relevant files of the newly created project are initially empty. Besides it is possible to change the name of an existing project file.

By default the 10 last used projects are held in this list. By clicking the button *Old Projects* a list of recently used projects opens and you can select your desired project file to work on. After highlighting the desired project click the OK button to open it. (Alternatively the choice can also selected by double click).



As soon as you click the button *Open Project* the following control elements are available again. The parameters and the elements of a newly created or existing project are definable now.



Project data

The parameters of the project are as follows:

Temporary Directory: (Optional) Within the program execution some temporary auxiliary files are created. The directory for these auxiliary files can be defined separately. In no valid directory is defined, the program uses the current project directory for this temporary files.

Project Info: (Optional) Here short description about the project can be entered.

Start directly: By activating this option the sub-programs like *relative orientation, space resection* etc.are started immediately as soon the corresponding button of the main menu is clicked.

Project Dimensions: In these fields the maximum number of images, points etc. are defined. By entering these values the accordant memory will be allocated for storing any single data of an individual point. Usually the default values are acceptable for normal projects and there is no change required.

For applying the changes made in this step click the *Save Project Data* button. Afterward the changes will be effective.

4.1 Project Dimensions

The memory of the computer can be partitioned among the individual data groups when required. If, for example, in a project an exceptionally big number of object points are measured, the memory allocated to points can be increased and the memory allocated to images can be reduced.

As mentioned before the default values of project dimensions are suitable for many practical projects, see the table beneath. The current dimensions are always maximum dimensions. This signifies, for

Images	50
Object points	1000
Models	500
Additional observations	100

example, that by default up to 50 images may be processed in a project.

When the project's dimensions exceed the defaults, accordant adaptations have to be made. Enter the new dimensions and save them by clicking *Save Project Data*. (After this the project has to be loaded again.)

✍ Through the menu item ***PHIDIAS | Project | Dimension*** it is also possible to change the project's dimensions.

4.2 Further Information about Project Management

The management of the projects has to bee seen directly together with the environment variables named *PHOCAD*. This environment variable gives the place where the initialization file is to be found (PHOCAD.INI). By the installation it is usually made sure that the named environment variable is automatically placed by every start of the program. So that complications are avoided.

It's also possible to enter the path of the file PHOCAD.INI manually in the operating system:

```
set PHOCAD=D:\PHOCAD\PHOCAD.INI
```

The path specification - as well as the name of the INI file - is basically optional. In this example the file PHOCAD.INI should be stored in the PHOCAD directory on drive D. At the program start the initialization file PHOCAD.INI is searched using the environment variables.

If the file PHOCAD.INI is not found, the program creates automatically a new one and an accordant message appears.

As a rule the initialization file PHOCAD.INI should be found using the environment variable PHOCAD at a central place.

In summary the project management is as follows:

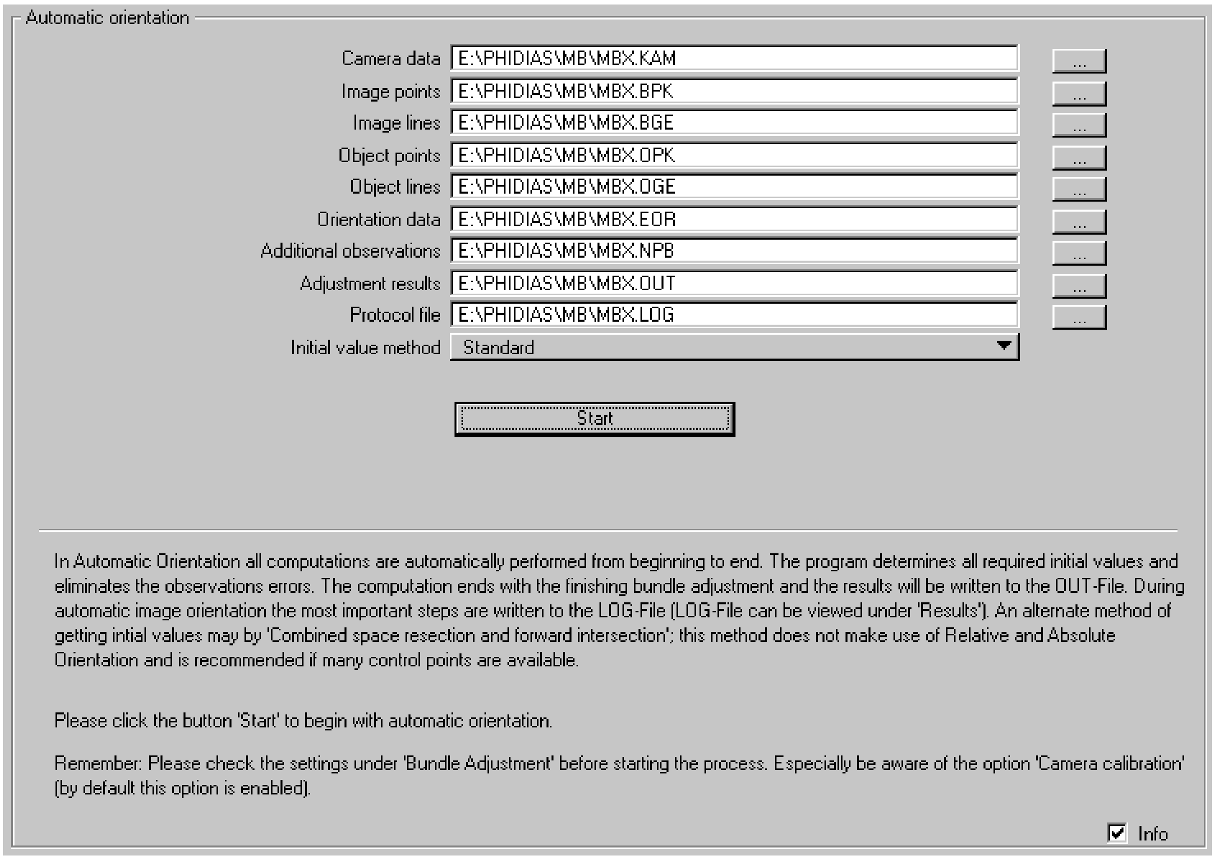
Element	**Purpose**	**Where to find**
Environment variable *PHOCAD*	Defines the storage place, where the initialization file PHOCAD.INI is to be found; this variable should be defined before starting the program.	System control of the operating system
File PHOCAD.INI	For the storage of the control data, which are valid independendly from the special project; by this, for example, the name of the current project and the projects which have been treated lastly can be found.	At a central place (defined by the environment variable *PHOCAD*)
Project file xxxx.PRJ	For storing those control data, which are valid for the current project.	Normally in the same directory as the remaining project files

Overview about the project management

The project and initialization files are normal ASCII files which can be edited by every editor program. This is not necessary basically and should also remain undone by the user. All necessary elements are set with the installation of the program and by the new creation of a project, the proper project management will be set.

✍ The aspects of project management shown in this section are less important for practical handling of the program. They should only serve as background information in case of possible difficulties.

5. Automatic Orientation



In the orientation program MBUN it is possible to do the whole process of orientation automatically. After preparation of object points and measurements of control and tie points, the activation of the **automatic orientation** follows the steps below (see also the figure above):

Input files are the first seven files, that are: MBX.BPK, MBX.BGE (opt)., MBX.KAM, MBX.OPK, MBX.OGE (opt)., MBX.EOR and MBX.NPB. The additional observations in MBX.NPB are optional (i.e. the NPB file can be missing) (see chapter 9).

Two procedures are available for performing automatic orientation distinguished by the determination of approximate values:

1. Standard method:

On this occasion, all approximate values are determined for orientation data, point coordinates etc. by the sequential application of relative, absolute orientation and space resection. Indeed this standard procedure is computationally relatively expensive; however, it delivers the most reliable results in most cases.

2. Combined space resection and forward intersection:

This procedure is useful mostly if relatively many control points or control lines are given. On this occasion, the procedure of *relative* and *absolute orientation* is not used at all, but all approximate values are determined by alternating space resection and forward intersection.

By the fulfillment of the space resection the orientation data and by forward intersection the object data will be calculated. This approach is quicker because of not being so calculation-intensive. Indeed, the results can be incompletely obtained because some images are not able to be oriented directly. Above all long-stretched objects with weak perspective and bad distribution of object (control) points can cause problems.

The automatic orientation calculation begins by clicking the *Start* button. On this occasion, the approximate values are determined for all unknowns and afterwards the bundle adjustment is applied and calculated. The user is informed, on this occasion, sequentially by status displays about the momentary activities.

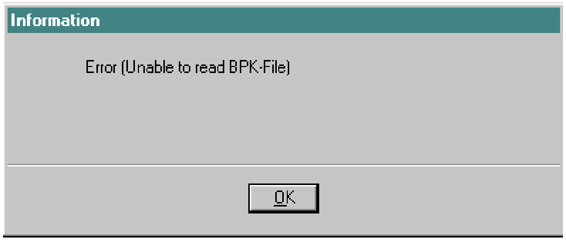
5.1 Canceling the Automatic Orientation

The automatic orientation can be halted by pressing of any key. So there appears a suitable message which informs about the halt. Then for continuing the procedures of orientation press enter key.

✍ Contingently it has to be waited for a little moment as far as the program will reach an occasion for ending the process.

5.2 Errors During Automatic Orientation

If any error appears during the automatic calculation, a suitable message appears in a display box.



Example of an error message (image coordinates could not be read evidently, because, e.g., the path does not exist)

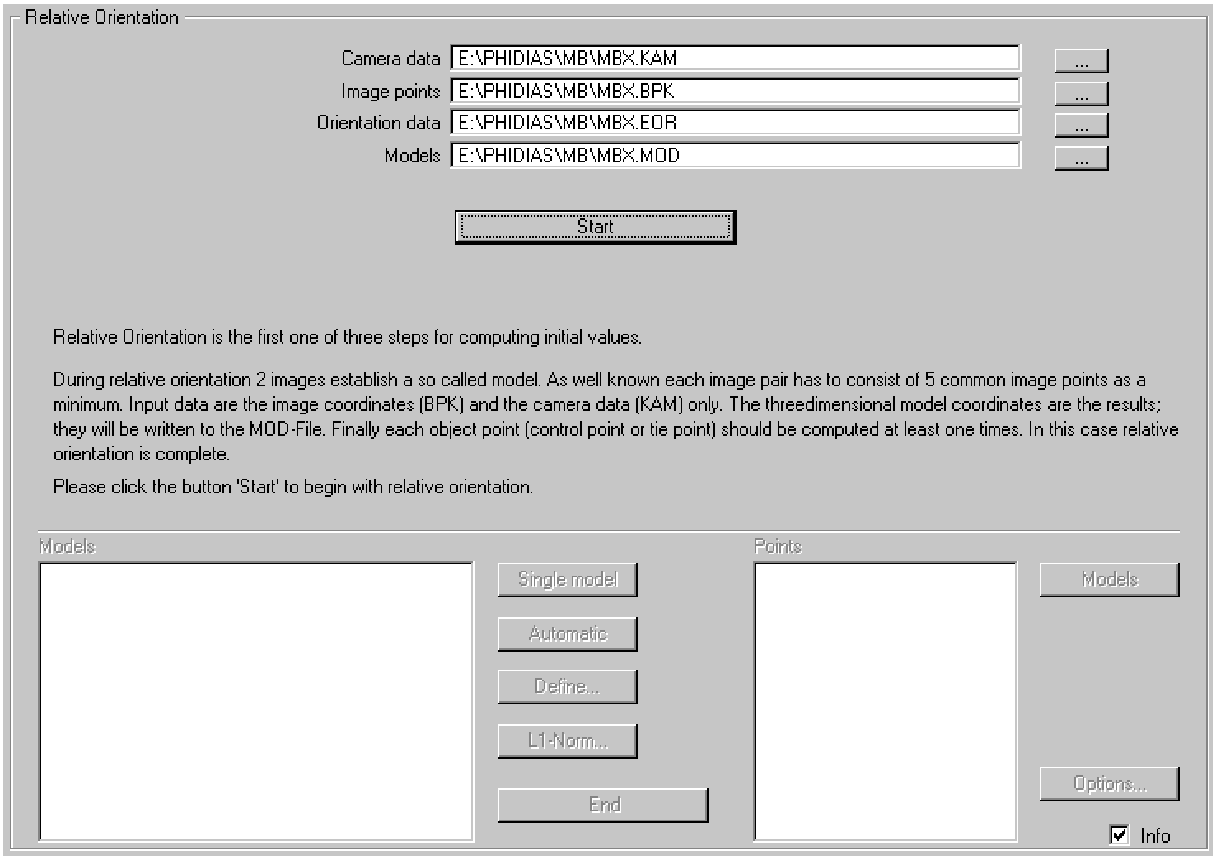
By clicking OK button the program will be continued.

5.3 The Log File

For figuring out the cause of some error messages occurred during the procedure of automatic orientation or any other aspects of the program, the user may refer to the LOG-file. By the helping comments existing in this log file the reason can be released. The instructions are given step-wise and the source of error is easily realized.

The LOG-file is accessible through the *Results* section (see chapter 11); instead of the name of the result file (OUT-file) the name of the LOG-file has to be used there or – as an alternative – by a usual editor the contents are visible.

6. Relative Orientation



For relative orientation four files are required:

MBX.BPK: Here are stored the coordinates of the image points which have been measured for the orientation.

MBX.KAM: It contains the data of one or more cameras. Each record represents one camera data set.

MBX.EOR: In this file the six parameters of exterior orientation exist and – only at this place – the assignment of the camera to the images is done.

MBX.MOD: The results of the relative orientation are stored in this file,the so-called model data. The extension MOD is the standard name from which only in special cases should become changed.

By clicking the *Start* button the procedure of relative orientation begins.

✍ The results are written into the MOD file only when the relative orientation is finished Then an appropriate dialog box appears.

During relative orientation the following methods can be distinguished:

1. Selection of image pairs using the sorted model list (see chapter 6.1)

2. Selection of image pairs using the object point list (chapter 6.2)

3. Automatic execution of relative orientation (chapter 6.3)

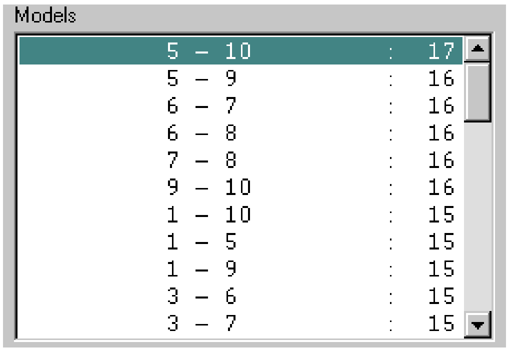
4. Relative orientation with manual defaults for approximate values (chapter 6.4)

5. Blunder detection using L1 norm calculation (chapter 6.5)

The different methods are described now in detail.

6.1 Selection of Image Pairs Using the Sorted Model List

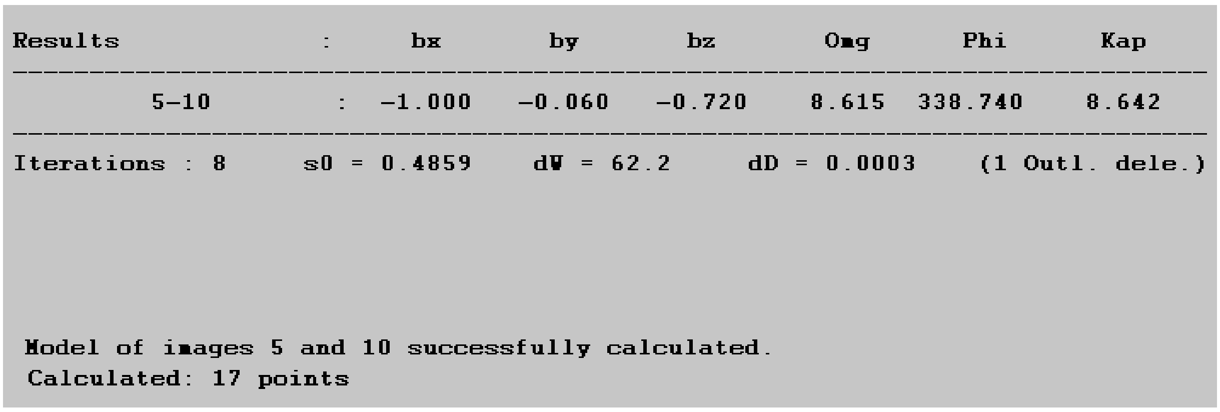
In the following it is assumed that the relative orientation has been started and all necessary data have been loaded. The list named *Models* now shows all photogrammetric models, which can be calculated theoretically. The list is sorted by the number of common image points.



List of the sorted image pairs (models): the number 5-10 means that the model is made up of image 5 and 10. About 17 points can be used to orient them.

6.1.1 Calculation of a Single Model

To calculate a single model, the suitable line becomes highlighted in the model list with a mouse click and then click on the button *Single Model*. Alternatively can be also pressed enter or double click on the appropriate line from the model list.



Results of the relative orientation (here from image 5 and image 10)

The relative orientation is calculated as a so-called *conjunction of successive photos*. On this occasion, as shown above, image No. 5 was oriented to image No. 10 using 17 tie points.

In the upper part of the window the results of the relative orientation calculation are displayed: these are the components of the base vector bx, by and bz as well as three rotation angles around which the image 10 is rotated against 5. The scale of the model is fixed considering the fact that a component of the base vector (mostly bx) gets the length 1.

The relative orientation is carried out in an iterative adjustment process. In this step the observations are image coordinates. In case of any blunder the program itself discovers it and then eliminates the accordant image points. The elimination continues until all gross errors are removed.

✍ As faulty determined image points are removed only temporarily, i.e. at a new calculation of the image pair the image points are available again. The exclusion of erroneous image points can also be done manually. (see chapter 6.6).

During relative orientation several *quality features* are calculated and the results of every model are stored in the MOD file. These quality features are in detail:

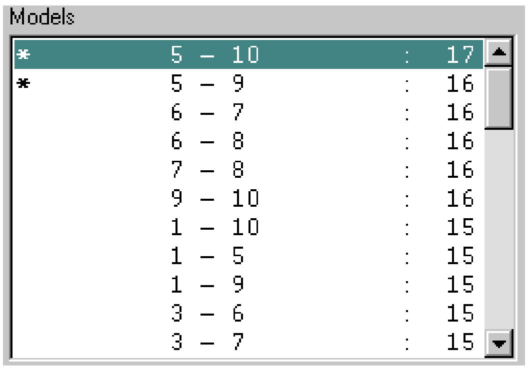
s_0: Standard deviation of the weight unit. According to experience a good value for this variable is smaller than 10, otherwise the model is not a good one.

dW: Averaged intersection angle of image rays in gon. This value should be possibly above 10 gon, better more than 15 gon.

dD: The average of the gaps which the image rays meet during the calculation of the model coordinates.

The previously described quality features are used with the automatic orientation to derive an optimal order of calculation. Hereby the quality features are assessed using different weights. In some cases the success of the orientation depends on the best order.

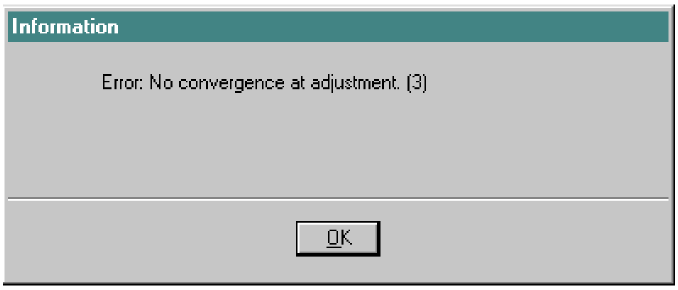
All model which could be calculated successfully are marked in the list:



Marking calculated models

6.1.2 Errors and Warnings During Relative Orientation

During the calculation of relative orientation a huge number of errors can appear which lead to an abortion for the current image pair. Then the user is informed by a short message with respect to that.



Error message during relative orientation (example)

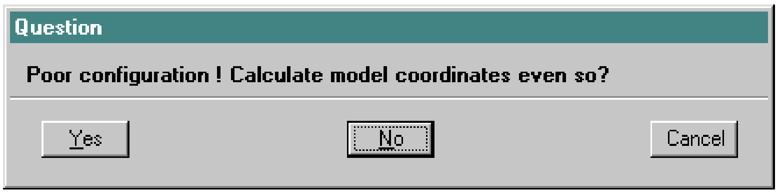
The failure of a relative orientation is often founded in the exposure geometry; that is mostly an image pair with nearly identical camera stations.

Sometimes the calculation of the relative orientation succeeds, but the result is poor and not really reliable. An accordant message appears in this case.

```
Warning: Poor configuration (s0>10.0 or dV<10.0).
Model probably poor.(Basis and z-direction nearly parallel)
```

Message in the case of poor relative orientation.

Additionally a further dialog box is opened and the user is prompted whether the model shall be calculated anyway. Mostly it is not recommended to use such models for orientation, because they may disturb the whole process seriously.



Further question if a model is probably poor and not reliable

6.1.3 Repeated Calculation of a Model

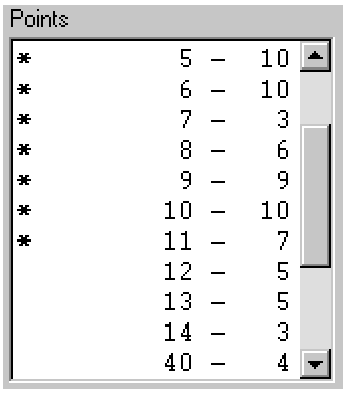
Every image pair which has been calculated successfully and has been stored is marked in the list of models (see chapter 6.1.1). If a model is selected once more for the calculation, a confirmation inquiry appears at first:

If a model was calculated already once, a confirmation inquiry appears

If *Yes* is clicked, the calculation takes place in this case and identical model data are stored repeatedly (the identical approach is assumed like the first time). Indeed this is not basically nor harmful neither profitable for orientation process.

6.2 Selection of Image Pairs Using the Object Point List

The list named *Points* shows all object points which exist in at least two images of the project and which therefore are computable as model points by relative orientation.



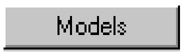
The list of the object points: all points which have already been calculated at least in one model are marked with an asterisk. The point No. 8 e.g. is found in 6 images.

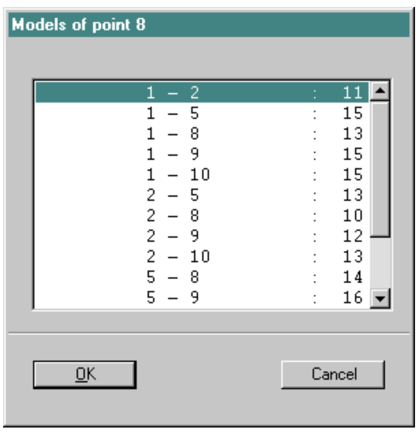
Every line consists of the point number and the number of the images in which this point has been measured.

✍ With larger projects it may take a few seconds to open the list, because it is first to be created and sorted.

6.2.1 Find Out all Models in which a Point is Computable

If a point is selected in the list of the object points and then the button *Models* is clicked, it appears another dialog box with all models in which the respective point is computable. With ENTER or with a double click on the appropriate point the same action will be done.





The model list referring to the point No. 8; i.e. the point 8 can be calculated in each of these image pairs.

6.2.2 Calculation of a Model

Now, select one of the models which you want to be calculated. By clicking the OK button, the relative orientation of the relevant image pair will be done.

According to the successful calculation of a model, the model is marked accordingly. In addition, the list of the already existing object points is updated and is also marked.

In case of clicking *Cancel* the dialog box is closed and no calculation will be done.

6.3 Automatic Execution of Relative Orientation

The orientation program provides the possibility of doing relative orientation automatically. This method is recommended normally.

6.3.1 Calling Automatic Orientation

The automatic implementation of the relative orientation is begun with the button *Automatic*. Then the user is informed on the screen constantly about the further way of the calculation.

After execution of the automatic relative orientation it is indicated how many models and points could be determined.

```
  1. Process:    32 Model(s)        21 Point(s)
  2. Process:     1 Model(s)         0 Point(s)
  3. Process:     0 Model(s)         0 Point(s)
  4. Process:     0 Model(s)         0 Point(s)
  5. Process:     0 Model(s)         0 Point(s)
  6. Process:     0 Model(s)         0 Point(s)


 Automatic calculation done. 6 process(es)
 Calculated: 33 of 45 models   21 of 21 points
```

Display after execution of the automatic relative orientation

6.3.2 Order of the Calculation

Within the automatic relative orientation the models are processed in a certain order. Here, two criteria play a role:

1. Generally, always the models with the most points are taken first, because the accuracy of determination is supposably highest.

2. Finally, the model calculation is processed in maximum 6 passes. These passes differ in the quality of the accepted models. In the first pass, the criteria are strongest, and get weaker by the following passes.

The quality criteria of the 6 passes are in detail:

1. Pass: Only models without or with only few outliers; the average *dW* of the image rays must be at least 10 gon. (The limit value of 10 gon is the default and can be changed in *Options* by the user; as well as the limit value, see also chapter 6.6.)

2. Pass: Now all remaining models with several outliers, but after elimination of the gross errors there remains redundancy; dW must be at least 5 gon. (However, the limit value for the standard deviation *s0* decreases to only 1/5 by which the requirements are raised.)

3. Pass: All remaining models with several outliers and remaining redundancy if the limit value *To* is doubled for the detection of a gross error; *dW* must be at least 10 gon.

4. Pass: All still remaining models with several outliers, with, after elimination of the latter, no more redundancy; *dW* must be at least 10 gon.

5. Pass: All remaining models which are from the beginning without redundancy; *dW* must be at least 10 gon.

6. Pass: All other models; nevertheless, the averaged intersection angle *dW* must be at least 5 gon.

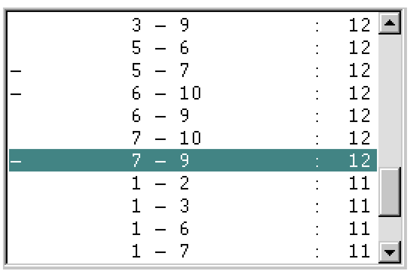
In all 6 cases the limit value for the standard deviation s0 has to be kept, i.e. this limit value must not be exceeded. The limit values for the averaged intersection angle and the standard deviation are both 10.0 by default; however, they can be changed by the user (see chapter 6.6).

6.3.3 Selection of Passes

The button *Options ...* opens another dialog box *Relative Orientation – Settings*. In this dialog box, among others things, individual processes (passes) of relative orientation can be switched off or on again. More explanations to this are in chapter 6.6)

6.3.4 Excluding Models from Calculation

During automatic calculation individual models can be excluded from calculation. To do this the respective lines are tagged in the model list by the minus key.



All models, which are not to be calculated, are tagged with a minus sign

The tags are removed again with the plus key or the space bar.

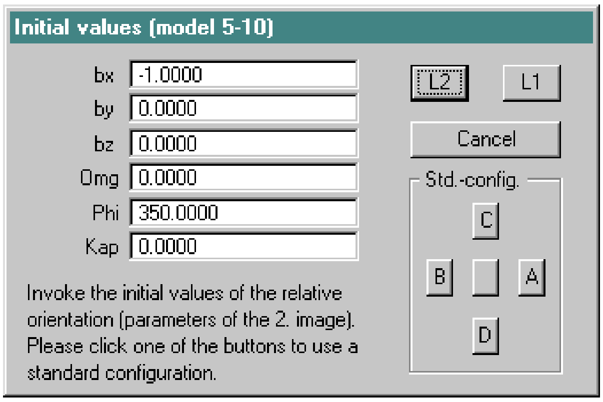
6.3.5 Abortion of the Automatic Calculation

The automatic relative orientation can be halted at any time by pressing any key. Then it is indicated how many models and points have been calculated until the time of the abortion.

6.4 Relative Orientation with Manual Defaults for Approximate Values

Because it may happen sometimes that the calculation of an image pair does not lead to a result, there is the possibility to define initial values manually. Then these initial values serve as approximate values for the conjunction of successive photos. The regular calculation can fail, for example, because the approximate values generated by the program are wrong or too inaccurate.

Another dialog box is opened after clicking the button *Define*.



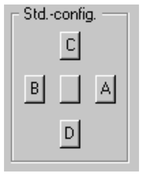
Setting approximate values for the relative orientation of an image pair (currently entered are the values for standard constellation B, thus the image 10 is "left" to image 5)

✍ Setting manually initial values for relative orientation requires a good understanding of the mathematical background of photogrammetric conjunction of successive photos. The user should become familiar with the topic in case by using technical literature.

6.4.1 Approximate Values for the Conjunction of Successive Photos

Now in the text fields approximate values can be entered for the successive image parameters of the second image. These parameters consist of the base vector (bx, by, bz) as well as three rotations (Omg, Phi, Kap) of the camera. The first image (here in the example No. 5) is fixed to define the coordinate system of the image with the origin Xo = Yo = Zo = 0.0 and the rotations Omg = Phi = Kap = 0.0. Then the position and the rotations of the 2nd image (here No. 10) is defined relatively.

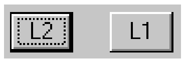
Because it is not quite easy to estimate correctly the base vector and the rotations of the second image, four standard constellations named A, B, C and D can be chosen. If one of these is clicked, the accompanying approximate values are set for bx, by and bz as well as Omg, Phi and Kap. With the standard constellation A the second image is, for instance, “to the right” of the first image, in which the term “to the right” means on the positive x coordinate axis of the fixed first image.



Contingently the user should try to get a successful relative orientation by variation of the initial values which also delivers reasonable results.

6.4.2 Calculation with Defaults

After the input of approximate values for the base vector and the rotation angles the calculation of relative orientation can begin. Thereby can be calculated either with *L2 Norm* or *L1 Norm* by pressing the respective buttons.



The *L2 Norm* (button L2) stands for the usual adjustment calculation (method of least squares). This is the standard method as it is almost always used in all program parts of MBUN (bundle adjustment). By clicking on the button L2 the usual single model calculation begins, starting with the given defaults. This corresponds to the procedure started by clicking *Single Model*, exept that now certain approximate values are given. The further program flow is hence as in a usual single model calculation (see chapter 6.1).

The *L1 Norm* is, on the other hand, a special method to search for blunders among the observations. Further information about L1 calculation is found in chapter 6.5. If the *L1* button is pressed, the L1 error search starts, using the current defaults. This may become necessary in particular cases, if, for instance, the L1 method does not converge.

6.5 Blunder Detection Using L1 Norm

Principally, in relative orientation it is searched for faulty observations by a statistical outlier test – like in all other program parts of MBUN –, and these faulty observations are excluded from the calculation if required. The results of relative orientation calculation are the parameters of the *conjunction of successive photographs*. Observations in the relative orientation are the coordinates of the common image points in a model. The judgment by this outlier test whether an observation is faulty or not is roughly based on the accompanying residuals which arises from the adjustment.

Unfortunately, the usual adjustment method called method of least squares, also L2 adjustment or L2 norm has so-called blurring characteristics. This means among other, that not in any case the truly blundered observations are discovered in the outlier test. With particularly big and/or many outliers this can lead to a failure of the adjustment.

Now with the L1 norm another procedure is available, exclusively dedicated to error search. In comparison with "usual" outlier test at the least square method, the L1 norm often leads even with very gross errors (like point mix-ups) to a good result, while the L2 norm already fails.

✍ The L1 norm is not a universal solution. It does not release the user from thoughtful planning the image mosaic with good geometrical intersection conditions and the careful realization of the measurements.

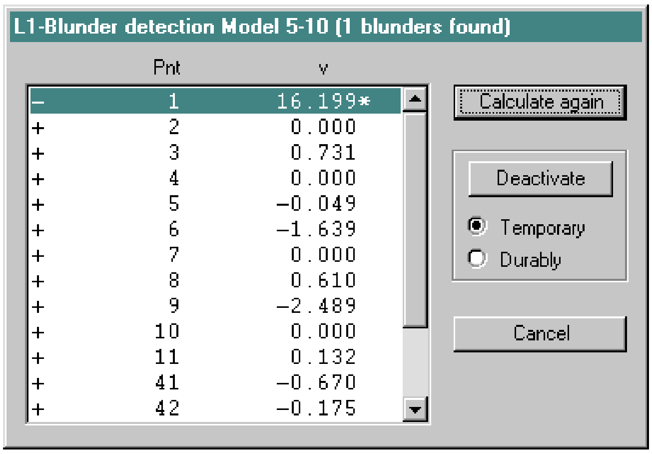
6.5.1 Blunder Detection

The L1 calculation of a model begins with clicking the button *L1 Norm*. If the calculation leads to results, these are indicated, i.e. the parameters of the successive image. These values differ in most cases more or less from those of the usual L2 adjustment; however that is quite regular.

```
Results     L1-Norm    :     bx       by       bz      Omg      Phi      Kap
------------------------------------------------------------------------------
         5-10          :   -1.000   -0.043   -0.729   7.539  338.432    9.623
------------------------------------------------------------------------------
Iterations : 7     1 blunders detected
```

Base vector and image rotations as result of the L1 calculation

In addition, a dialog box with the results of the blunder detection opens.



Dialog box with the result data of the L1-blunder detection (the point 1 is declared here as faulty)

In this dialog box for each image point the correction "v" is shown as it results from the L1 calculation.. The size of "v" from the L1 norm directly corresponds to the magnitude of the measuring error so it is not related to the L2 adjustment.

A number of the values in this list will be always 0.0, what is founded in the characteristic of the procedure. If "v" exceeds a certain amount, the point is marked by an asterisk and is known as faulty. At the same moment the corresponding line will be tagged by a minus sign. As distinguished from L2 error search, where per pass always only one point should be eliminated, in L1 norm all faulty observations can be found at the same time. Thus all marked points can be excluded from calculation all at once. The L1 calculation is normally carried out only once.

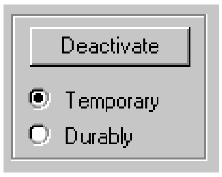
6.5.2 Deactivation of Image Points

The dialog box with the results of the L1 calculation shows the list of the image points. All points, whose residual "v" has exceeded from a certain amount are automatically marked with a minus sign. These points can be deactivated with the plus and minus keys of the keyboard independently or vice versa. Alternatively the activation status can be changed with the mouse and also by a double click on the particular line. The minus sign signifies that the marked point is not taken into account in the next calculation (see chapter 6.5.3).

The points with '+'-and '–' marks have the first priority in the next calculation. If a calculation is done with the same models later (L2 or L1 calculation), these points are available again.

Besides, single image points can be deactivated temporarily and permanently as explained below:

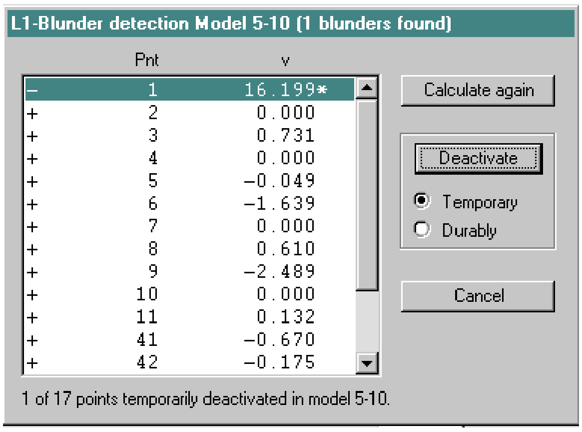
Temporary: Temporary deactivation implies that the deactivated points are no more used during the relative orientation. Only if the relative orientation is quitted and is carried out once more, the image points are available again.



Durably: The durable deactivation marks the respective points in the image point file (BPK file) as inactive. It means that these points are no longer used in the other aspects of orientation like absolute orientation or frame orientation. The durable deactivation can be revoked only with *Edit Data* (chapter 9).

✍ Deactivation of a point causes that particular point to be deactivated not only locally but also globally in other models in which the point exists. For instance, if the point was deactivated in model 5-10 simultaneously this point is not active in model 5-8 or 3-10 and is missing.

After the definition whether the deactivation should occur permanently or temporarily click on the button *Deactivate*. Then at the lower edge of the dialog box you will be informed that the deactivation procedure has completed. As long as the dialog box remains open, deactivation can be repeated, if desired, a point can be made available again by the '+' sign.



The dialog box after the deactivation: in this example an image point, the point no. 1 was excluded temporarily from relative orientation.

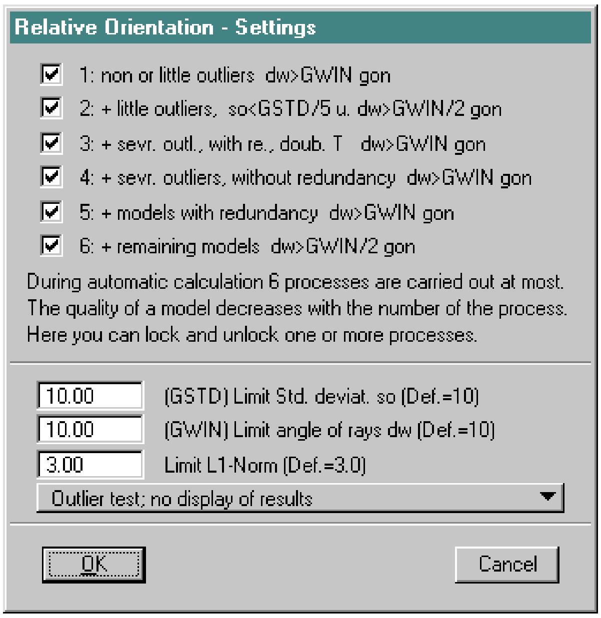
6.5.3 New Calculation after the L1 Norm

The L1 norm is generally only a procedure for outlier search. Indeed the well-known parameters of the *conjunction of successive images* are also to be calculated, but on them the calculation of the actually wanted model coordinates should not be based. That is why still a common L2 adjustment (new calculation) is done finally.

This new calculation will be started by clicking the *Calculate again* button. Because here a usual single model calculation takes place, the statements in chapter 6.1 apply accordingly. As mentioned before, only the points which are marked in the list by a '+'- sign are used in a new calculation. Decisive is only the tag in this list, a previous temporary or permanent deactivation (see also chapter 6.5.2) has no effect on the current recalculation.

6.6 Settings for Relative Orientation

The button *Options* opens the dialog box for adapting defaults for relative orientation. The dialog box *Relative Orientation – Settings* will be opened after clicking this button and this window provides different setting possibilities.

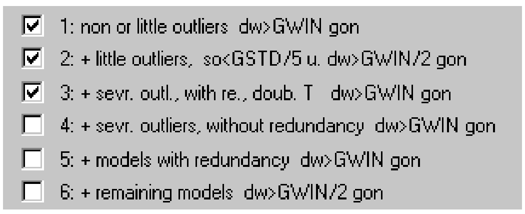


Dialog box for the settings of relative orientation

After clicking the OK button the modified settings will take place.

6.6.1 Excluding some Steps in Automatic Calculation

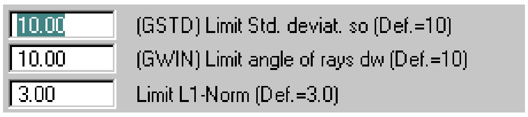
As described in chapter 6.3, the models are achieved from an automatic relative orientation progress through six passes. In the first pass the best qualitative model and in the last the worst models are calculated. Here at this window you can check or uncheck the pass by a single click.



✍ If an orientation does not reach the desired results, you could try to exclude worse models form the orientation by switching off the "less demanding" procedures (e.g., nos. 4 to 6).

6.6.2 Limit Values

There is the possibility to adjust the limit values for the standard deviation s0 (GSTD) and the averaged intersection angle (GWIN). Both values become normal at 10.0. For taking good results the value GSTD is reduced and GWIN is increased. Generally the two value work inversely.

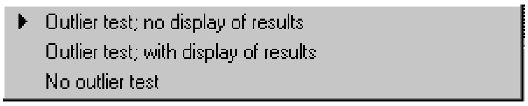


In automatic orientation by the two limit values GSTD and GWIN the quality properties of the calculated models may varied to get good results. Single faulty models can be troublemakers for the whole image orientation and lead it to a failure.

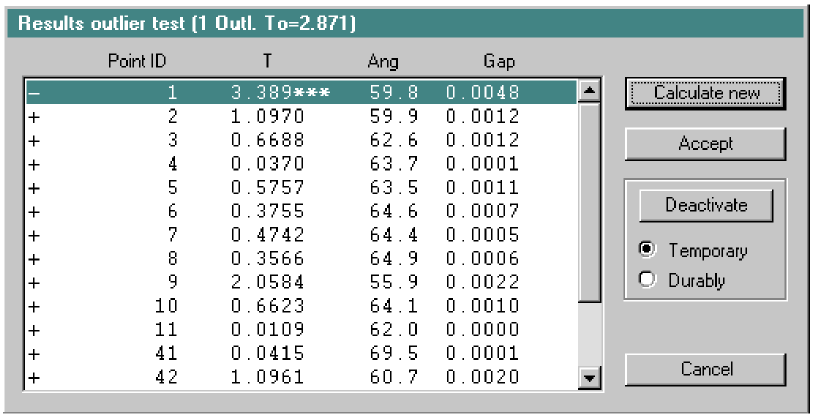
Here, in addition, the limit values can be changed in the process of searching for error using L1 norm. The default is 3.0 and the value is defined in relation to the base of the conjunction of successive photos. (In MBUN the base is so standardized that either bx or by are set to 1.0.) The limit value refers - indirectly - to the amount of the residual distance of the intersecting but skew image rays. If a residual from the L1 calculation exceeds the amount determined here, the particular point is treated as erroneous.

6.6.3 Blunder Detection and Display Results

Concerning blunder detection there are three options possible: *blunder detection with displaying results*, *blunder detection without displaying results* and *no blunder detection*.



By choosing the second option *Outlier test; with display of results* the intermediate results of the outliers test for each image pair can be checked. Then, it appears during the single model calculation (chapters 6.1, 6.2) at first a further dialog box.



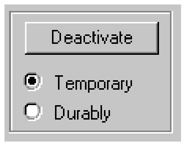
Displaying results of blunder detection

For each image point is displayed, besides the outlier test statistics *T*, the respective intersection angle (Ang) and the gap between the skew rays (Gap). To examine an error the test statistics T is decisive: If this exceeds the limit value T_0, a gross error is probable. The current limit value T_0 used depends on the number of image points and stands in the title line of the dialog box (here `T0 = 2.871`).

The in each case biggest error is marked with a minus sign by the program. In principle further image points can be inactivated or activated again by typing a minus respectively a plus sign or a double click of the mouse. Usually only one point is marked, the one with the biggest error. Because in principle the outlier theory requires elimination of single observations.

If blunders were found, a recalculation should be started by clicking the *Calculate new* button. Then relative orientation will be done again, but this time without the point or points marked by '–'. Usually, as said before, there should always be only one image point eliminated in each recalculation, even if there are several blunders. This procedure is repeated until there are no more blunders.

Finally the result is stored by clicking the *Accept* button. Only now the calculation of the model coordinates takes place and the model is marked by an asterisk in the list.

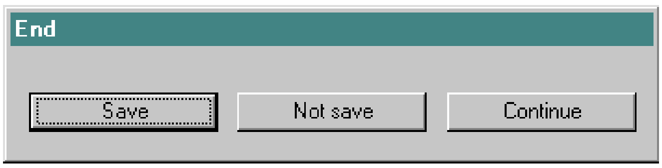


Independently of the iterative elimination of outliers and repeated recalculation image points can be deactivated temporarily or permanently. See chapter 6.5.3 above.

In some special cases the outlier test can be deactivated completely (option *No outlier test*). For example, if a lot of image points have been measured and one can be sure that single faults will have no negative impact on the result of relative orientation. The calculation process will be much more faster then, because eliminating of all gross errors does not happen.

6.7 Finishing Relative Orientation

The relative orientation will finish by clicking the *End* button. Then the user is asked whether to save the results. The relative orientation may still be continued now by clicking the *Continue* button.



Dialog box for finishing the relative orientation

7. Absolute Orientation

The absolute orientation is used in MBUN for four different calculations:

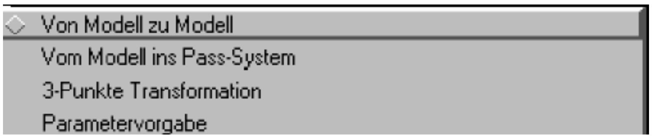
1- Choosing one of the models as a reference and transformation of the remaining models into the coordinate system of that reference model **(From Model to Model),** chapter 7.1

2- Transformation of one or several models into a unique reference coordinate system **(Models into Object System),** chapter 7.2

3- Creating a coordinate system with model points **(3-Points System),** chapter 7.3

4- Selecting one of the object points arbitrarily according to given parameters **(Parameter Default),** chapter 7.4

Accordingly *types of transformation* there is pull down menu in which you can select the method of absolute orientation. As shown below:



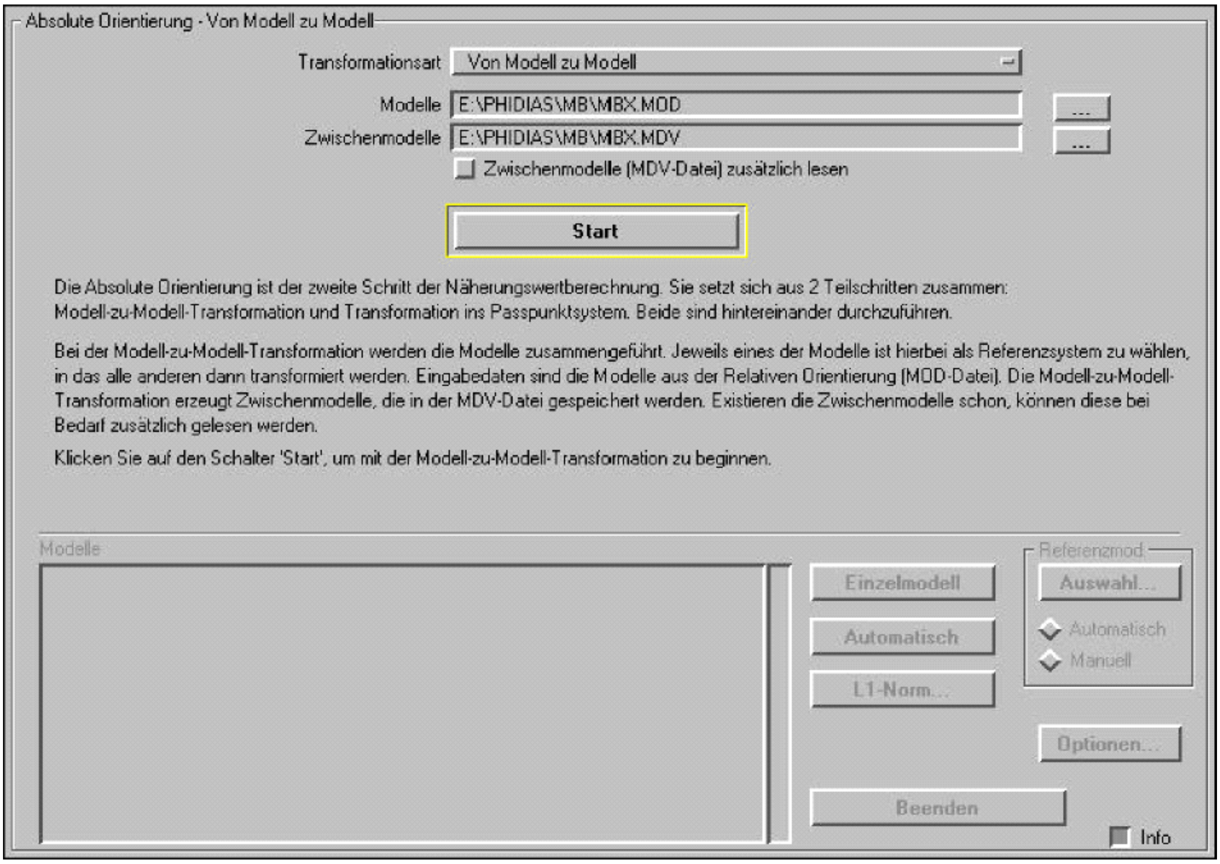
Transformation procedures of the absolute orientation

For orientation of an image mosaic mainly the first two menu items are used. At first the single models from the relative orientation are transformed with **From model to model** into a common coordinate system. Thereafter these points have to be transformed with **models into object system** into the control point coordinate system**.**

If no control points exist, the second step can be also replaced with **3-points transformation**.

Basics of image orientation are explained in chapter 14 *"basics of image orientation"*.

7.1 Absolute Orientations – Model to Model



This type of transformation needs two files:

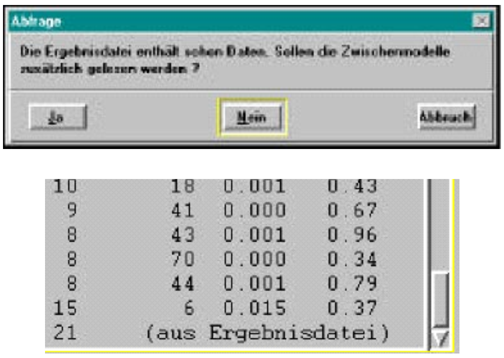
MBX.MOD: This file is called mode file and consists the model data form relative orientation.

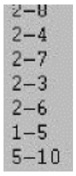
MBX.MDV: The results which own temporary character and are stored normally in a file with the extension MDV.

The transformation calculations between the models are started by clicking the *“start”* button**.**

7.1.1 If the Result File Already Exists

If the absolute orientation has been already carried out, it is possible to use formerly transformed points in addition to the earlier points. The already available point coordinates are in the MDV file.





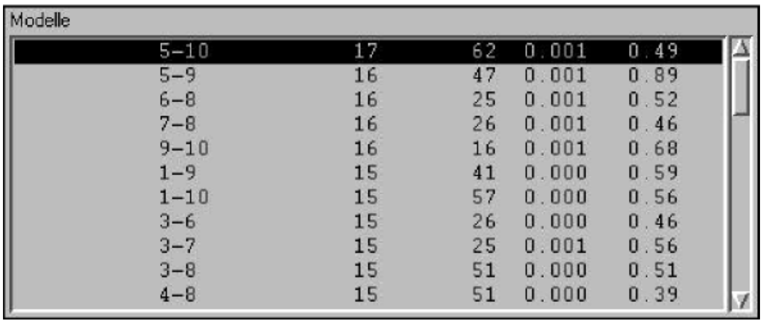
If the user wants to use these points, the appropriate check-box “intermodels” must be activated by left click of the mouse.

However, the program asks once more whether the available result should be read. Then with *“Yes”* answer the reading process takes place.

As a rule the old data should not be read from the result file.

7.1.2 Choosing the Reference Model

After starting of Model-to-Model transformation, the model data comes up at first which is from the relative orientation, (as well as perhaps old transformation results, see chapter 7.1.1.) and will be indicated in a list as shown below:



List of the models

With the model number and the quantity of the points the accuracies are also indicated. These are:

dW: average angle between the image rays (e.g., 62 gon)
dD: average gap between the generally skew image rays (e.g., 0.001)
s_0: Standard deviation of unit weight from the adjustment (e.g., 0.49)

Each line represents a model from the MOD file. When also the result file (MDV file) was read (see chapter 7.1.1), the models from this file are added to the list.

In this example one more model (5-10 with 21 points) from the MDV file was read.

The models from the result file can be treated like the remaining models.

For the further approach it is important whether the reference model is selected manually or automatically.

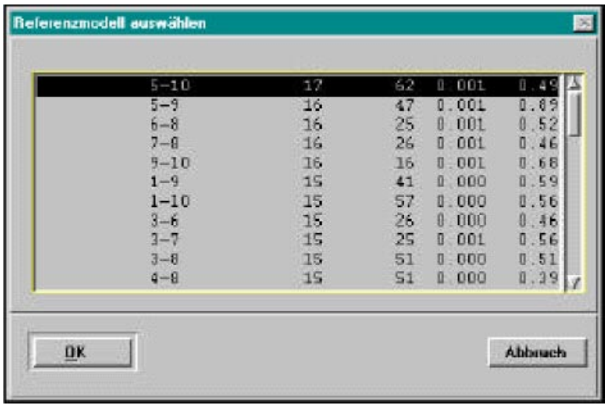
7.1.2.1 Manual Selection of the Reference Model

First set the option in “manually” or “automatically” by click of the mouse. Then by clicking the *“choice”* button a dialog box with all available models appears on the screen. The desired model is to be selected in this list and then the button "OK" must be clicked.

Selection of the method

For achieving optimal results, the models should be selected by the following criteria:

- At the beginning of the list there are the models which are generally better than those at the end because they have first been calculated using relative orientation. (This assumes of course the automatic calculation of the model data, see chapter 6.3).



Choosing the reference model

- A good model comprises as many points as possible.

- The average angle between the image rays by which the model points are determined should be close to 100 gon.

- The average gap should be very small.

- The s_0 from the adjustment is low in a good model.

7.1.2.2 Automatic Selection of the Reference Model

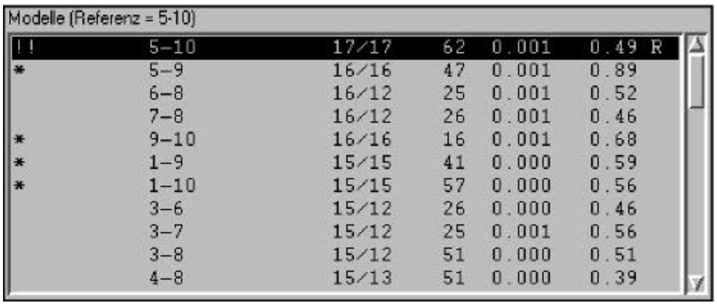
For the automatic selection of the reference model the option *"automatic"* must be selected. Once the button *Choice* is clicked the reference models will be determined by the program. Here the most optimum model as a reference will be selected. On this occasion, the accuracy criteria from the relative orientation are used.

Selection of *Automatic* method

Now after the manual or automatic method of selecting reference model all remaining models can be transformed in the coordinate system of the select model.

7.1.3 Transformation of the Models to the Reference System

After the determination of the reference model this is marked in the model list:


Modelle (Referenz = 5-10)

!!	5-10	17/17	62	0.001	0.49	R
*	5-9	16/16	47	0.001	0.89	
	6-8	16/12	25	0.001	0.52	
	7-8	16/12	26	0.001	0.46	
*	9-10	16/16	16	0.001	0.68	
*	1-9	15/15	41	0.000	0.59	
*	1-10	15/15	57	0.000	0.56	
	3-6	15/12	26	0.000	0.46	
	3-7	15/12	25	0.001	0.56	
	3-8	15/12	51	0.000	0.51	
	4-8	15/13	51	0.000	0.39	

The model list after selection of a reference model (here 5-10)

Each line consists the number of the points, how many points exist all together in the respective model and how many of it are identical with the points of the reference model.
For example: 16/12 signifies 16 points all together, 12 of it are the same as the ones in the reference model.

In addition, the new list contains some further marks:

- The well-chosen reference model is marked by two exclamation marks. In addition, it is put an 'R' at the end of the line.
- Furthermore, in cases some other models are marked. This mark signifies that all points of the respective model are already transformed or exist in the coordinate system of the reference model.

Through this the user can overview at any time the progress of absolute orientation.

With the transformation of individual models, as with the choice of the reference model, it is to distiguish between manual and automatic procedure.

7.1.3.1 Manual Model Transformation

First click on the model which you want to transform and highlight it. Then click on the *"Single model"* to start transformation calculation.

7.1.3.1.1 Calculation of the Transformation Parameters

From a mathematical point of view the absolute orientation is based on a spatial Helmert (overdetermined similarity) transformation. As result the 7 transformation parameters are displayed after each successful model transformation:

```
Ergebnisse   :  m         Xo         Yo         Zo        Omg       Phi       Kap
------------------------------------------------------------------------------------
                1.91      0.51       0.55       3.63      6.957   395.640   400.117
------------------------------------------------------------------------------------
Iterationen: 4          s0 = 0.003                                  (1 Ausr. entf.)



 Transformation von Modell 6-8 erfolgreich durchgeführt.
 Hinzugenommen wurden: 4 Punkt(e)
```

Screen report after transformation of a model

In the preceding example the 6-8 model was transformed. Further 4 points could be transferred in the common coordinate system of the reference model.

At this stage, as with the relative orientation, the program also carries out a statistical test on big errors. If any error is discovered, the program will eliminate it gradually. A point is taken out in each case of the transformation, until no more outliers are determined.

> Ther may be cases with so many blunders, that finally less than 3 usable object points in a model remain available. Because at least 3 points are necessary, the program aborts, showing an appropriate message.

The models list is updated after every transformation and further marks generally appear at the beginning of every line as shown below:

Modelle (Referenz = 5-10)

!!	5-10	17/17	62	0.001	0.49	R
*	5-9	16/16	47	0.001	0.89	
**	6-8	16/16	25	0.001	0.52	*
*	7-8	16/16	26	0.001	0.46	
*	9-10	16/16	16	0.001	0.68	
*	1-9	15/15	41	0.000	0.59	
*	1-10	15/15	57	0.000	0.56	
*	3-6	15/15	26	0.000	0.46	
*	3-7	15/15	25	0.001	0.56	
*	3-8	15/15	51	0.000	0.51	
*	4-8	15/15	51	0.000	0.39	

The models list after successful transformation of model 6-8.

The iterative transformation of other models is continued, until possibly at the beginning of each line is shown a double mark "**".

5-9	16/16	47	0.001	0.89	*
6-8	16/16	25	0.001	0.52	*
7-8	16/16	26	0.001	0.46	
9-10	16/16	16	0.001	0.68	*
1-9	15/15	41	0.000	0.59	
1-10	15/15	57	0.000	0.56	*
3-6	15/15	26	0.000	0.46	*
3-7	15/15	25	0.001	0.56	
3-8	15/15	51	0.000	0.51	
4-8	15/15	51	0.000	0.39	*

Modelle (Referenz = 5-10)

!!	5-10	17/17	62	0.001	0.49	R
**	5-9	16/16	47	0.001	0.89	*
**	6-8	16/16	25	0.001	0.52	*
**	7-8	16/16	26	0.001	0.46	*
**	9-10	16/16	16	0.001	0.68	

Double marks indicate the completeness of the model transformation.

7.1.3.1.2 Marking the Transformed Models

In the list of the models, marks "**" are appeared after every perfectly transformed model.

- The first asterisk * at the beginning of a line says that all points which are found in a model were transformed into the reference system.
- The second asterisk * indicates also computation of the orientation parameters of the images.
- The end marked generally by an asterisk "*" (an exception: only at the reference model stands an 'R') states that the particular model was transformed successfully in the reference system.

Modelle (Referenz = 5-10)

!!	5-10	17/17	62	0.001	0.49	R
**	5-9	16/16	47	0.001	0.89	*
**	6-8	16/16	25	0.001	0.52	*
**	7-8	16/16	26	0.001	0.46	*
**	9-10	16/16	16	0.001	0.68	*
**	1-9	15/15	41	0.000	0.59	*
**	1-10	15/15	57	0.000	0.56	*
**	3-6	15/15	26	0.000	0.46	*
**	3-7	15/15	25	0.001	0.56	*
**	3-8	15/15	51	0.000	0.51	*
**	4-8	15/15	51	0.000	0.39	*

Model list after transformation of all models into the reference model (here 5-10)

7.1.3.1.3 Handling of Non-Coherent Image Mosaics

A non-coherent image mosaic is a set of models none of which got an asterisk mark, so there is no transformed model after absolute orientation. In some cases it can appear that one is not able to transform all models to a reference system. Then the reason is generally an insufficient connection among the photos of an image mosaic. All models which cannot be transformed have no mark at the end of the line then.

In these cases another reference model must be determined for models without asterisk. Afterwards the process goes on exactly as described in the chapters from the 7.1.3.1.1 to 7.1.3.1.2.

In special cases even more than two blocks exist in the image mosaic and the procedure of choosing reference model and transform models to it must be repeated as often..

7.1.3.1.4 Order of the Model Transformation

After a reference model has been defined, the remaining models are transformed as described into the reference coordinate system (see chapter from 7.1.3.1.1 to 7.1.3.1.3). In especial cases the success of an image orientation can depend on the order of model transformation particularly at badly configured image mosaics.

In the selection of the next model for the calculation of the transformation parameters (see also chapter 7.1.3.1.1) and selection of the reference model, the same criteria should be taken into account (see chapter 7.1.2.1). The most favorable model must be chosen on the basis of the number of the points and the goodness criteria from the relative orientation.

The mentioned criteria are weighted within the automatic model transformation (chapter 7.1.3.2).

7.1.3.1.5 Re-Transformation of a Model

A model can be selected repeatedly for transformation. The program makes no suitable further inquiry different than the relative orientation. The renewing choice has no influence on the storing of the transformation results in the result file (mostly MOD file) because the creation of this files takes place in the first step (see chapter 7.1.6).

Quite often a model must be transformed twice, so that the orientation parameters of the images are also transformed (chapter 7.1.3.1.2). Only in that case both star marks "**" appear at the beginning of the relevant line in the models list.

7.1.3.1.6 Error Messages During Model Transformation

During the calculation the program encounters some interruptions which lead that particular part of program to an abortion. Then, in conjunction with the abortion, appears a short message which informs the user about it.

Example of an error message

The program is continued by pressing the *"OK",* button in these cases.

7.1.3.2 Automatic Model Transformation

The transformation of the models into the reference coordinate system can be also carried out automatically.

7.1.3.2.1 Implementation of Automatic Transformation

After the reference model has been selected (see chapter 7.1.2), the user must click on button *“Automatic”*.

Then the models are transformed in the reference system. During the calculation there is an on-line report which informs the user about the momentary activities of the program.

Then at the end a message is given in which the integer of the transformed models is announced:

The number of the transformed models

7.1.3.2.2 Order of Transformations

The program always tries to use the best models first in the transformation of the models into the reference system. So it is guaranteed that for the object point coordinates optimal results are obtained.

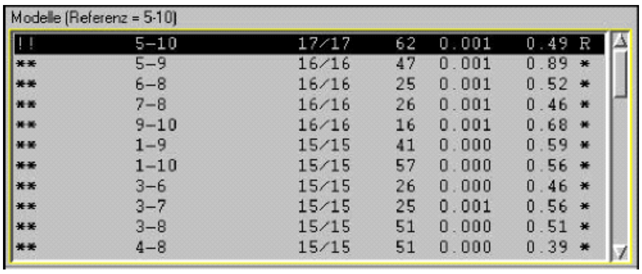
The evaluation of the models is done by weighted consideration of several criteria (see also 7.1.2.1):

- Number of points
- Average angle between the image rays forming the model
- Average residual distance of the skew image rays
- Standard deviation of unit weight from the adjustment

If the image mosaic consists of several blocks and therefore more than one reference model is necessary (see chapter 7.1.3.1.3), the program recognizes this situation and tries to repeat the cycle until possibly all models are transformed.

7.1.3.2.3 Marks after Automatic Model Transformation

After successful execution of automatic model to model Transformation all models are declared with a double mark at the beginning of each respective line:


Modelle (Referenz = 5-10)

!!	5-10	17/17	62	0.001	0.49	R
**	5-9	16/16	47	0.001	0.89	*
**	6-8	16/16	25	0.001	0.52	*
**	7-8	16/16	26	0.001	0.46	*
**	9-10	16/16	16	0.001	0.68	*
**	1-9	15/15	41	0.000	0.59	*
**	1-10	15/15	57	0.000	0.56	*
**	3-6	15/15	26	0.000	0.46	*
**	3-7	15/15	25	0.001	0.56	*
**	3-8	15/15	51	0.000	0.51	*
**	4-8	15/15	51	0.000	0.39	*

Double marks “**” after automatic model transformation

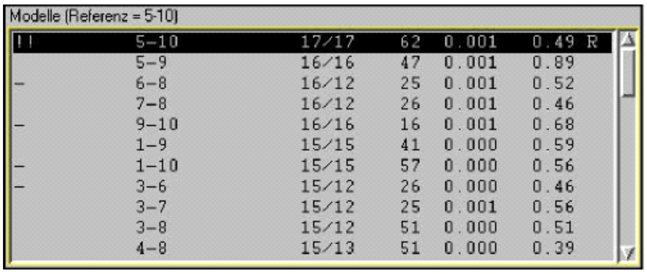
These marks give a hint to the fact that the object points of the models and the orientation parameters of the images could be transformed in the coordinate system of the reference model.

If the transformation misses over a model, a minus sign is put to the relevant line which represents that particular model.

In these cases the cause should be investigated within the manual model transformation (chapter 7.1.3.1).

7.1.3.2.4 Exclusion of Individual Models from Transformation

If some models should be excluded from calculation, the respective lines must be marked by a minus "–"in the model list.



Mark of models with the minus mark (inactive) and it can be changed to a plus mark (active) by pressing space bar.

The deactivated models are not involved in automatic model to model transformation. The deactivation can be cancelled by pressing the space bar key.

7.1.3.2.5 Breaking off Automatic Model Transformation

The model to model transformation accomplishes very fast and very big project it may take a little longer. Automatic transformation process can be broken off by pressing any key at any time. In this case relevant message appears:

The message after abortion of transformation

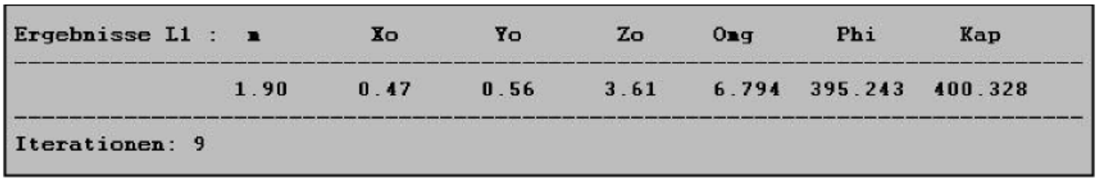
The automatic enforcement of the model transformation should be chosen preferably because, the achievement of best results is guaranteed.

7.1.4 Searching for Errors Using L1 Norm

Some remarks were already explained in chapter 6.5 about the theoretical and operational background of the L1 norm. These descriptions are not going to be given here because they are the same as absolute orientation. Therefore, the following explanations concentrate upon the program-technical service within the scope of the absolute orientation.

7.1.4.1 Execute Blunder Detection

By clicking on the button *"L1 norm"*, the program begins the calculation of models in the model list. As with the normal transformation with the switch *"single model"* the results, i.e. the transformation parameters become indicated. Because the L1 norm is used only for the blunder detection, the transformation parameters are at the second priority.

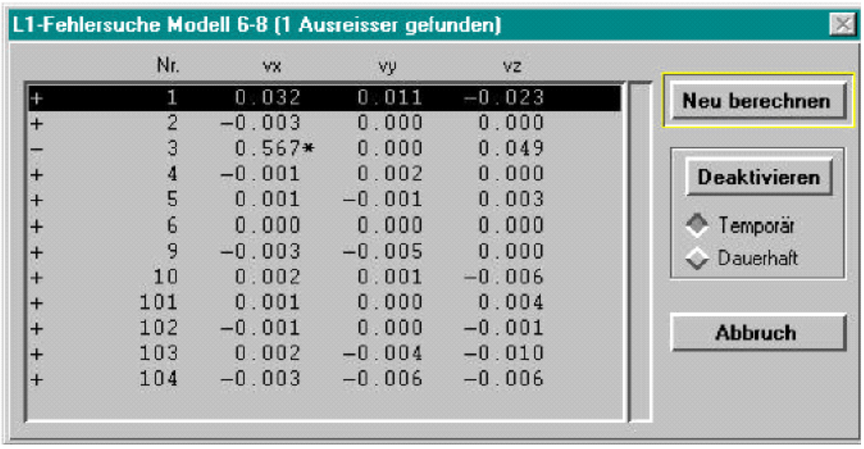


Ergebnisse L1 :	m	Xo	Yo	Zo	Omg	Phi	Kap
	1.90	0.47	0.56	3.61	6.794	395.243	400.328

Iterationen: 9

Display of the transformation parameters with the L1 calculation

In addition, the dialog box with the results of the blunder detection opens.



	Nr.	vx	vy	vz
+	1	0.032	0.011	-0.023
+	2	-0.003	0.000	0.000
-	3	0.567*	0.000	0.049
+	4	-0.001	0.002	0.000
+	5	0.001	-0.001	0.003
+	6	0.000	0.000	0.000
+	9	-0.003	-0.005	0.000
+	10	0.002	0.001	-0.006
+	101	0.001	0.000	0.004
+	102	-0.001	0.000	-0.001
+	103	0.002	-0.004	-0.010
+	104	-0.003	-0.006	-0.006

Dialog box with the results of the L1-blunder detection

Dialog box with the results of the L1-blunder detection: vx, vy and vz indicate the possible errors in measurement process if these values exceed form a certain amount they would be marked by a minus "–" before them.

With the L1-blunder detection results (vx, vy, vz) are determined to every object point and some points own always the value 0.0. This variation vector (vx, vy, vz) gives directly explanation about a possible observation error. Observations are 3 coordinates of the object points with the absolute orientation. Therefore vx, vy, vz are errors in the coordinates.

The limit value for the judgment whether the coordinate is blundered or not can be adjusted through *"options"* by the user (see chapter 7.1.5).

In principle the user can activate with '+' and '–' keys some object points or vice versa.

After the execution of L1-norm (blunder detection) and indication of faulty object points, a new calculation should take place again by clicking the button *"New calculate"*. With the new calculation only the object points are involved which own a plus sign in the list. The program carries out a normal model transformation.

The new calculation – i.e. the usual adjustment by method of least squares – must always follow the L1 norm; however there are no errors. The transformation parameters from the L1 norm are not used generally in the absolute orientation for the conversion of the object points into reference system. The L1 norm exclusively functions the role of releasing outliers.

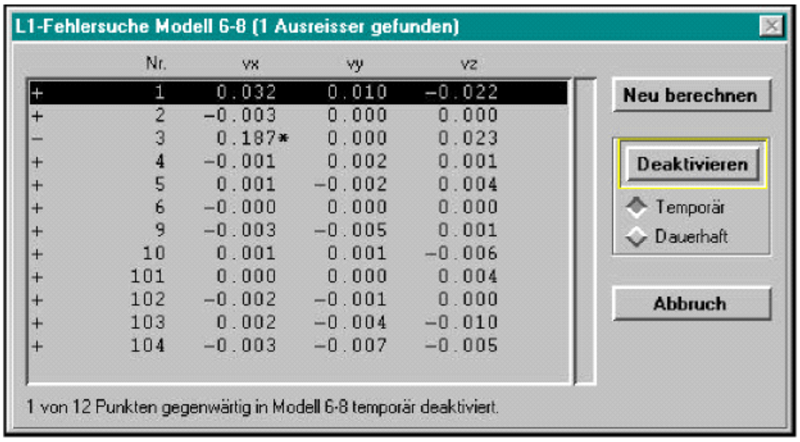
7.1.4.2 Temporary or Permanent Deactivation of Object Points

The deactivation of the object points (with the minus sign) first has been done by new calculation after L1-norm calculation (see the proceeding chapter). Independently the object points can be deactivated with the button *"Deactivate"* temporarily or permanently.

Temporarily: temporary deactivation signifies that the deactivated points are no longer used during the absolute orientation. If the absolute orientation is quitted and is called once more, the object points are available again.

Permanently: The lasting deactivation marks the respective points in the MOD file as inactive points. This means that the object points are not taken into account in any case that the MOD file is used. If the relative orientation is carried out once more a new MOD file is generated then the deactivation is canceled again. The permanent deactivation endures until the new generation of MOD file.

The deactivation takes place by clicking *"Deactivate"* button, afterward in the lower part of the dialog box is informed about it.

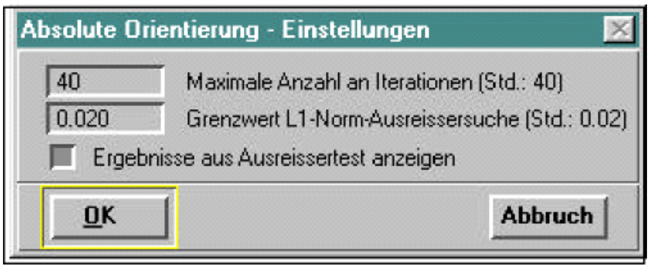


The dialog box *L1-blunder detection* for the temporary deactivation of an object point (here No. 3)

The object points with a minus sign are always deactivated.

7.1.5 Settings for Absolute Orientation

By clicking the button *"Options"* the dialog box of absolute orientation settings appears. Then different settings can be changed.



Settings of absolute orientation

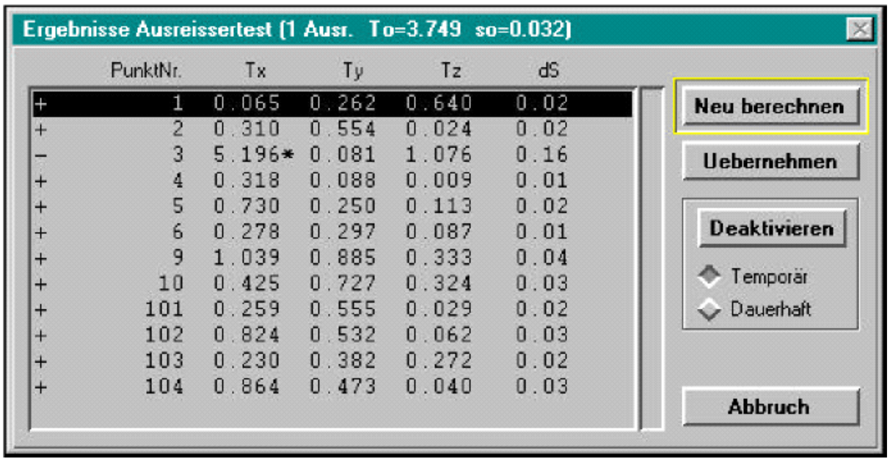
7.1.5.1 Limit Values

Iteration: the absolute orientation is based mathematically on a spatial similarity transformation whose parameters are determined by adjustment. The adjustment takes place based on iteration and the maximum number of iteration is up to 40 rounds. This number should be sufficient in almost all cases. Only in rare cases one it is need to increase or decrease the iteration number.

L1 norm: In absolute orientation it is particularly used in searching for gross errors in the object coordinates, see chapter 7.1.4. The results of this process come in form of some difference vectors (vx, vy, vz) called residuals. If any of these residuals exceeds a certain amount or a limit value determined by user, the respective points is assumed as a faulty one. The limit value must be considered with model to model transformation in relation to model finalization. The model finalization is fixed in the relative orientation. In MBUN the model finalization is defined by the fact that a component of the base, namely bx and by are set to 1.0. Now the limit value with the L1-blunder detection is to be chosen in proportion to these dimensions. The standard default of 0.02 might be a suitable size. The user can change this value based on experience.

7.1.5.2 Display Results

By the switching on "*results from outlier test*|" option, after the outlier test another window containing the results appears:



Display of the results of the outlier test

In this dialog box the test statistics Tx, Ty, Tz as well as the linear residual gap dS are shown for every object point. If a test residual exceeds the limit value "To", it will be marked by an asterisk. There is a short report of "s_0" and "T_0" in the title bar of this window.

The point with the biggest residual is marked. The minus sign signifies an inactive point which becomes effective with a next new calculation. The new calculation will be done by clicking *"new"* button then the model transformation is repeated.

Basically one should repeat the new calculation until no more errors are found or should deactivate equally several points manually; however one should exclude only one object point in every round, normally the biggest error. By the way if the switch *"results from outlier test"* is not selected, automatically the program carries out the removal of the gross errors step by step.

By clicking the button *"accept"* (the results) the model transformation is accepted and is accepted. Then the dialog box is closed.

To a certain extent the faulty points can be eliminated temporarily or permanently.(see also chapter 7.1.4.2 for details).

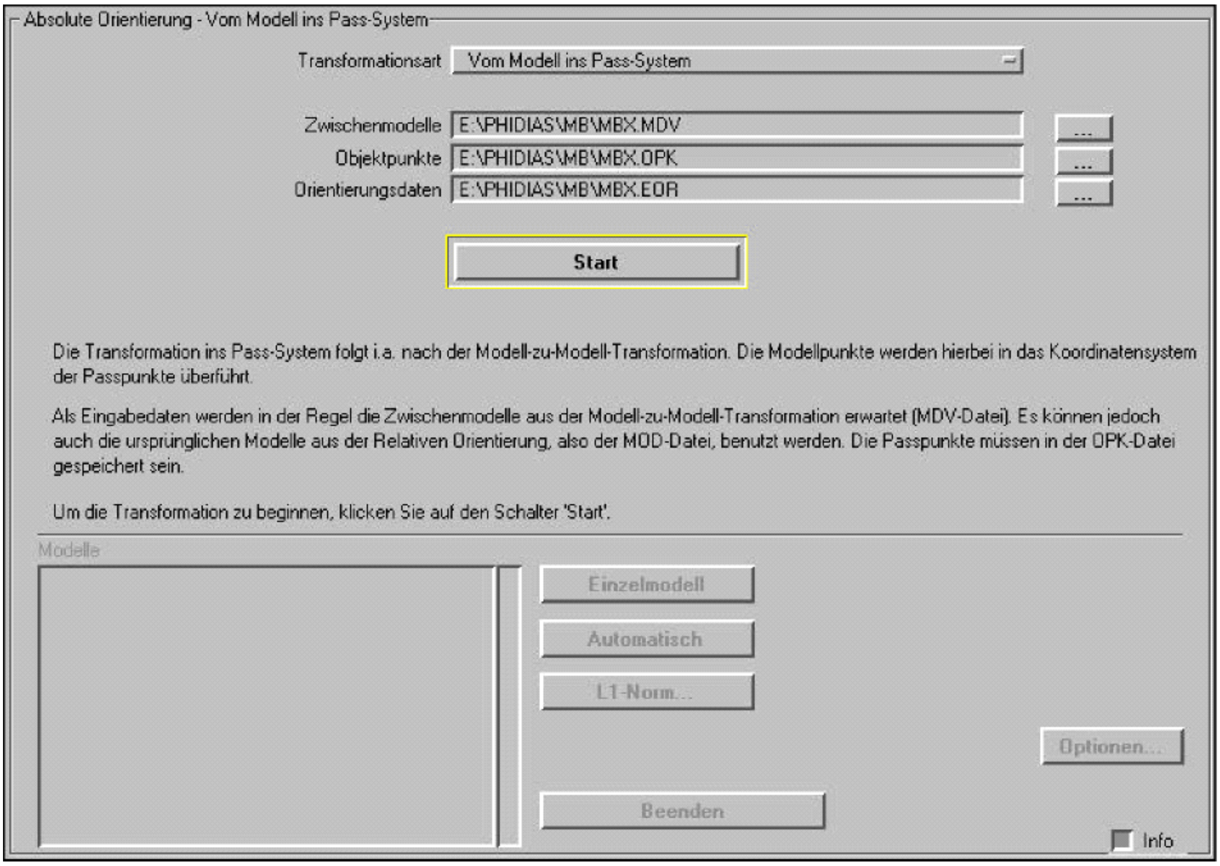
7.1.6 Finishing Model to Model Transformation

This section of transformation of model data into the coordinate system of a reference model (model to model transformation) can be terminated with the button *"Finish"*.

Inquiry at finishing model to model transformation

For storing the result data in the result file, the user must confirm the question accordingly. The absolute orientation is continued with the button *"Continue"*.

7.2 Absolute Orientations – Models into the Control System



The execution of this transformation assumes that the different models from the relative orientation (chapter 6) have been brought in a common coordinate system through the process of model to model transformation (chapter 7.1). Therefore all object points can be transformed into the object coordinate system.

For the transformation of the object points two files are used:

MBX.MDV: as the input data the transformed model data from the model to model transformation are required (chapter 7.1). The standard extension for this file name is MDV

MBX.OPK: the control points which stay normally in a file with the extension OPK. All calculations to certain object points are added in this file.

The transformation begins by clicking *"start"* button.

7.2.1 Transformation of the Object Points into the Control System

After starting a list of models appears in which exists the contents of file MDV.

List of *Models* for transformation in the control point coordinate system

Because the "model to model transformation" has been carried out according to chapter 7.1 - only one model is available in models list, called the reference model. In this example model No. 5-10 was selected as a reference model and all other model data were transformed on this model.

If the image mosaic consists of several blocks and more that one reference model were selected for each block, you can find more models in this model list.

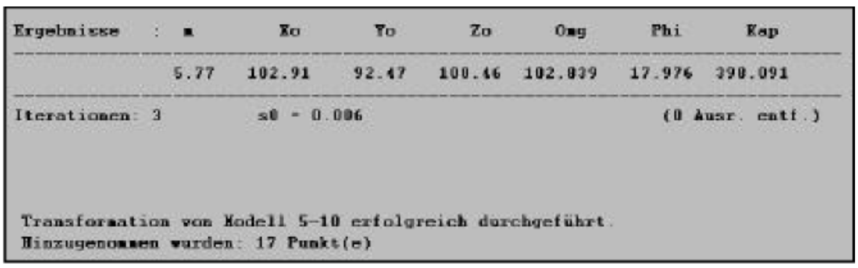
In this example the information signifies that a total of 21 object points are in MDV file which are transformed in the object coordinate system. Furthermore a total of 4 identical control points have been read in the control point file (OPK file) with which the transformation parameters are determined. At leas 3 points are necessary for carrying out the transformation.

Now it can be chosen to proceed either manually or automatically. Preferably one will manually execute the transformation because only one model is to be processed.

7.2.1.1 Manual Transformation

The calculation of the transformation parameters is begun with the button *"Single model"*. Then the marked model is transformed in the control point coordinate system.

Within the scope of this calculation it is automatically searched for outliers and if necessary the elimination of faulty points is carried. At the end, after the successful transformation the results are announced.



Results after the transformation of the model points in the control point coordinate system

After successful execution of model transformation to control point coordinate system, respective models (in this example just one model) are marked by double asterisks.

Marks after transformation

These marks declare that the object point coordinates and the orientation data of the images could be transformed successfully in the control point coordinate system.

7.2.1.2 Automatic Transformation

The automatic execution of this section of calculation is unnecessary in most cases because - as explained - only one model is transformed. Nevertheless, the automatic calculation can be begun by clicking the button *"Automatic"* which delivers then the same results.

It is to be pointed out to the fact that towards model to model transformation if several models are to be transformed, no special order is kept. Since the single models are processed independently from each other.

> **The automatic** calculation is aborted if there are less than 3 control points in the object point file (OPK file) (see chapter 9.3.1). In this program all new points (NP) are used as tie points for the transformation. In the log file appears an appropriate remark then.
>
> With manual procedure the object points are not relabeled automatically. The transformation cannot be done then with less than 3 points. As a solution further object points first have to be declared as control points with *"Edit Data"* (chapter 9.3.1).

7.2.1.3 Searching for Errors Using L1 Norm

With the button *"L1 norm"* a separate search for gross errors takes place in the data material. This is a similar process to model to model transformation and mathematically there is no difference in between. Therefore, the approach and the tips which are described in chapter 7.1.4 can be applied directly here.

The limit values concerned by L1 norm are identical to the ones pointed out in chapter 7.2.3.

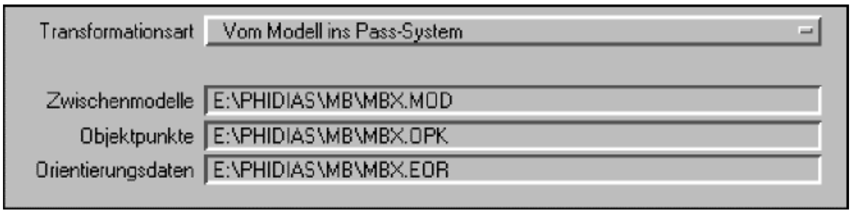
After execution of the calculation the coordinates of the object points whose image coordinates have been measured in the images are transformed in the coordinate system of the control points.

7.2.2 Direct Transformation of Models into the Control System

Moreover the models coming from the relative orientation can be transformed in the coordinate system of the control points directly and without the inter-step “model to model transformation” (chapter 7.1).

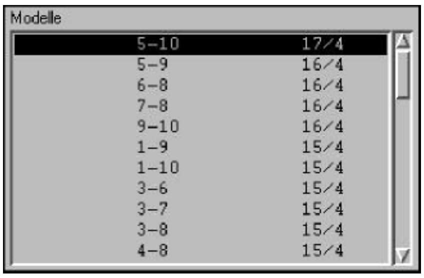
The direct transformation of the model data will be rarely applied because many object points may remain without approximate values. Hence, first of all model to model transformation should always be achieved (chapter 7.1) and then the transformation in the object system (chapter 7.2) is carried out.

In case of direct transformation the MOD file (instead of the MDV file) is given in the input mask as an input file:



Direct transformation: for 'inter-models' the name MOD (instead of MDV)is given to the model data file which is from relative orientation (MOD file instead of MDV) is given.

After starting of the calculation section the list of all models from this file will appear.



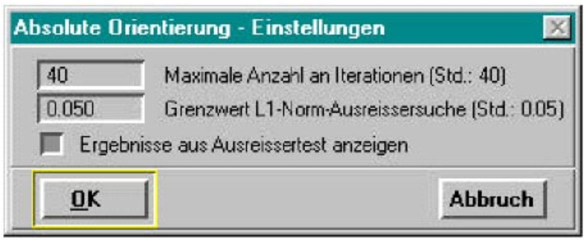
The models list from the MOD file for direct transformation; some models cannot be transformed because they contain less than 3 common points (e.g., 2-5).

The problem in this approach is that some models are not transformable because less than 3 common points are available. Therefore, some object points remain disregarded.

The further approach of transformation is described in chapter 7.2.1: the transformations can be carried out manually or automatically (see chapter 7.2.1).

7.2.3 Settings for Absolute Orientation

The button "Options" opens the dialog box *"Settings"*, which already explained in chapter 7.1.5 completely. Basically the same dialog elements are also available here.



Settings of absolute orientation

The definition of the maximum number of the iteration and the activation/deactivation limit for the display of outlier results are completely identical with those in chapter 7.1.5. Changing these two options in model to model transformation, affects setting of the transformation of models to the control coordinate system and vice versa.

The situation is a bit different with the *limit value* in the L1 blunder detection, because this must be regarded in proportion to scale of the models. As stated in chapter 7.1.5.1 the model to model transformation uses the scale of the models from the relative orientation. At the transformation to the control system the error search is based on the dimensions of the object system. Therefore a slightly different limit value should be set. The program supposes by default a coordinate error, if the limit value 0.05, thus 5 cm in the object system, is exceeded.

The limit value 0.05 for that kind of absolute orientation was determined based on our own, empirical considerations. It should be adapted in particular cases, according to experience.

7.2.4 Finishing the Transformation

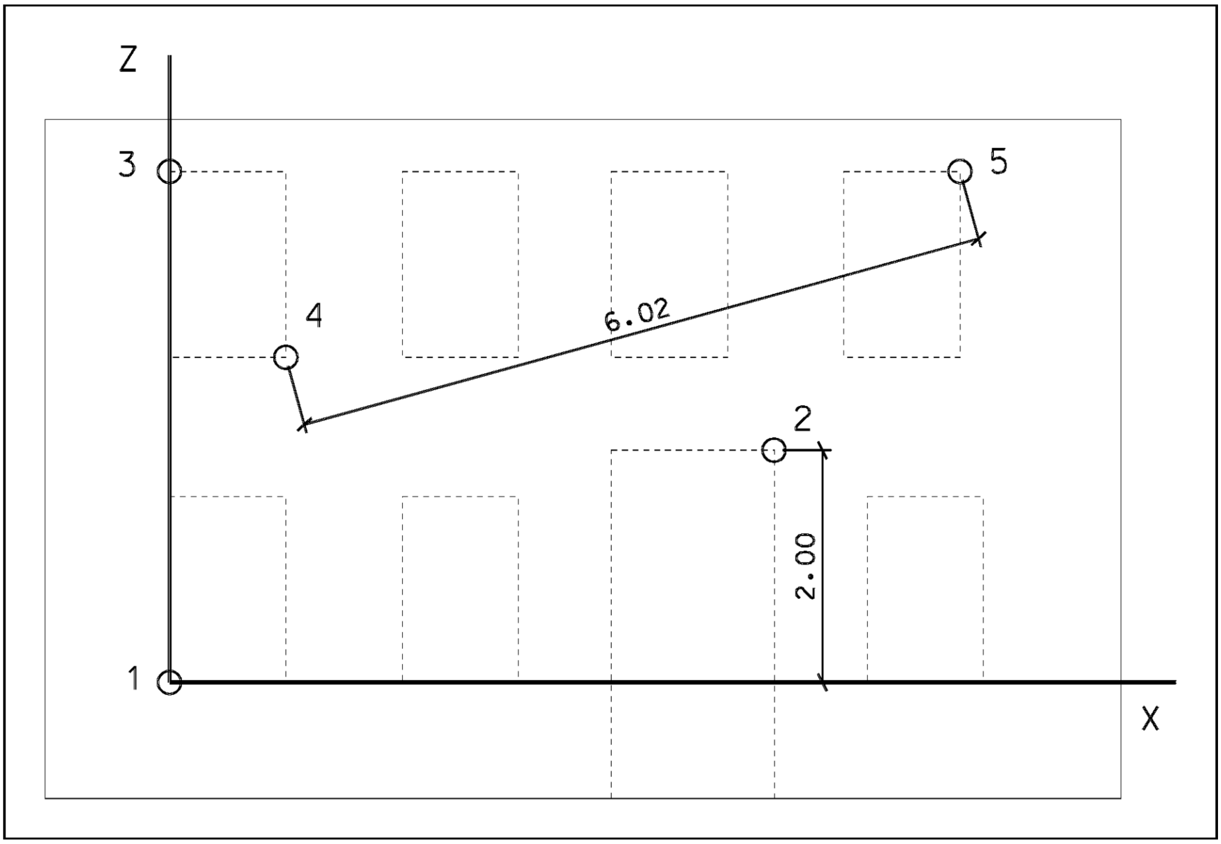
By clicking the button *"Finish"* this part of program will terminate. For saving the results at this section click on the button "*Save*" over the dialog box which appears after clicking "Finish" button. You can also continue transformation by clicking "Continue" button.

In case of clicking "*Save*" button the results will be stored in control point file.

Dialog box of finishing transformation

7.3 Absolute Orientations – 3-Points System

This transformation is primarily helpful, if no control points are available. The model points determined by the relative orientation can be brought by 3-point transformation into a desired position. This signifies, for example, that the point aggregate is leveled and at the same time is brought to an object-related scale.
Often the object points lie on a flat surface with little offsets, for example, on the object facade. The following figure makes this clear.



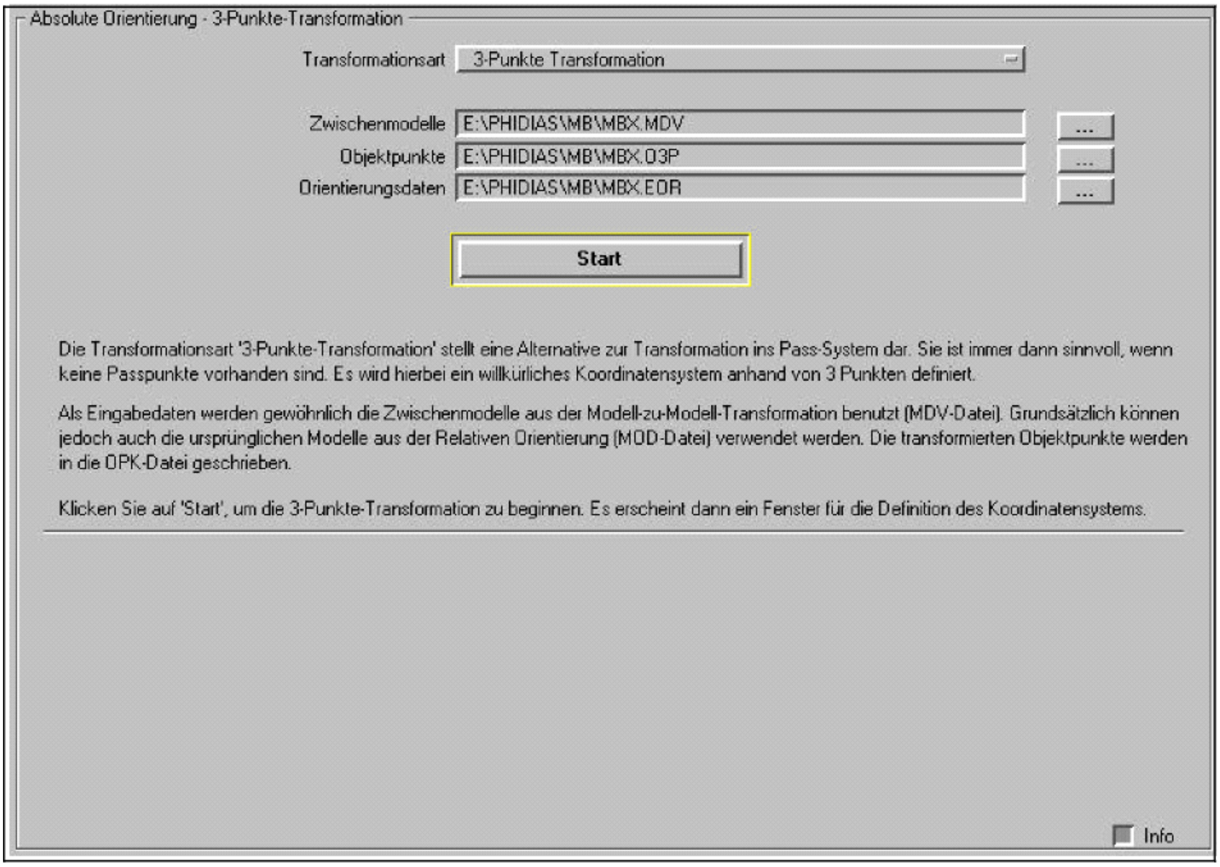
Drawing of a building facade as an example of the 3-points transformation

In this example the model points should be transformed under the following points of view:

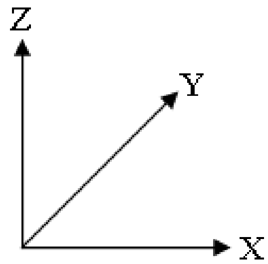
1. The origin should lie in point 1 and get the coordinates (100, 100, 100).

2. The positive X axis should lie horizontally along the building facade. Point 2 lies indeed in the same plane as the X and the Z axis, but exactly 2 m above.

3. The Z axis should go vertically upwards. The point 3 lies perpendicularly above point 1, so that the Z axis must go through point 3.



4. The Y axis comes as a complement to make a three-dimensional right-handed system. Therefore Y axis runs vertically to opposite direction of to the façade of the building.



5. The model points should be brought to the scale of the object. So at least one distance is necessarily required and was measured in this example (here it is the distance of point 4 and 5 which is 6.02 m).

7.3.1 Calling 3-Points Transformation

The 3-points transformation needs the following files:

MBX.MDV: as the input data the transformed model data from the model to model transformation are required (chapter 7.1). The standard extension for this file name is MDV

MBX.O3P: in this file the transformation results - the coordinates of the new stored model points - are written; actually this is the object point file (OPK) but in order to avoid probable confusions another file extension was selected for this file (O3P).

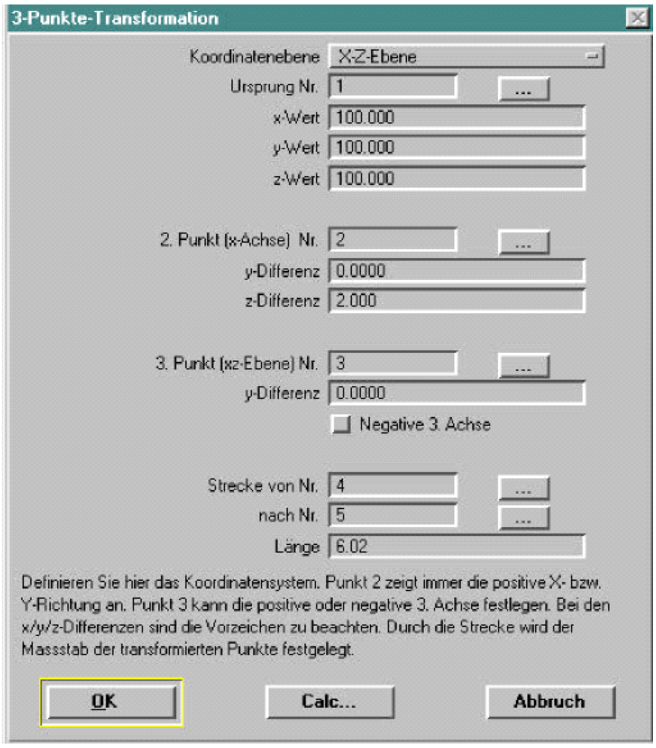
MBX.EOR: exterior orientation parameters were stored in this file from relative orientation section.

The MOD file can be used as an input file instead of MDV file from the relative orientation. Indeed, in this case only the first model which is found in the file is read.

Also the object points are possible as input data (OPK file). The object points must be only in the data format of the OPK file of MBUN (see chapter 13 *data formats).* Take care that in this case the result file does not get the same name.

7.3.2 Inputs for 3-Points Transformation

After *the start* of the 3-points transformation the following dialog box is opened.



The entities used in defining a coordinate system with the 3 points for transformation

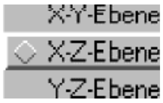
The new coordinate system is defined on the basis of 3 points. The type of the coordinate plane (X-Y, X-Z or Y-Z) which is fixed by these 3 points can be chosen in this dialog box. The first point functions as the origin, the second one determines the direction of the positive X axis. At the end, Y-axis is determined depending on the selected plan (X-Y, X-Z or Y-Z).

> The input data fix the coordinate system uniquely, i.e. without overdetermination. Thus, faulty definition parameters cannot be recognized by the program. Then the model points are transformed to a wrong position.

With the input of the point numbers and distances (differences to the axes of coordinates) the following specific features are to be noticed, where in some cases the sign is important.

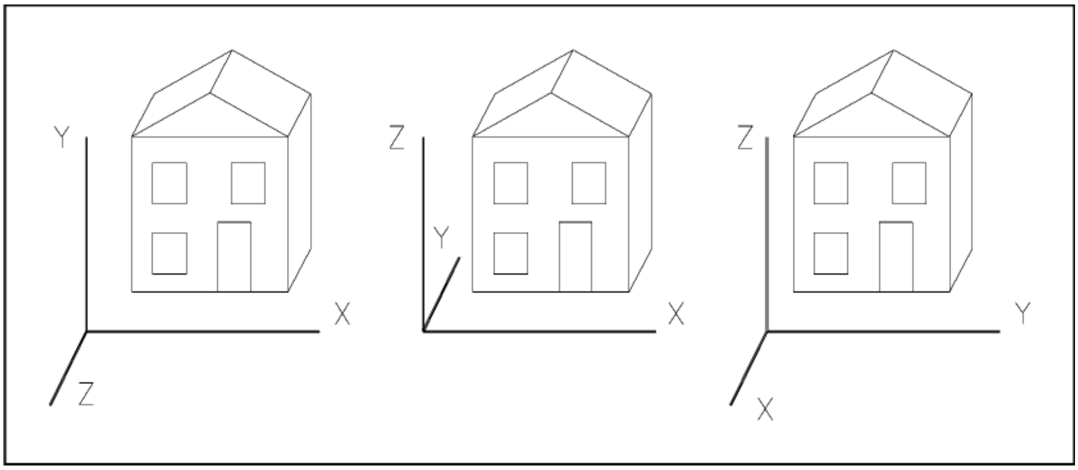
7.3.2.1 Type of Plane

By three points a spatial plane is unambiguously defined as everybody knows, provided that these points do not lie on a common straight line. In the 3-points transformation the coordinate planes of the spatial Cartesian object coordinate system (X-Y, X-Z or Y-Z planes) are used as planes. The type of the plane can be chosen through the menu *"Coordinate Plane"* as shown below.



Options for selecting type of plane

In the definition of coordinate system by 3 points it is to be guaranteed that the coordinate system forms a right-handed system. This point of view plays a role, in particular, towards the distances to the axes of coordinates (see chapter 7.3.2.3). The following image makes it clear, the storage of the coordinate systems and the adjustment of the axes of coordinates using a plane facade of the building. The well-chosen coordinate plane should lie in parallel to the building front wall.

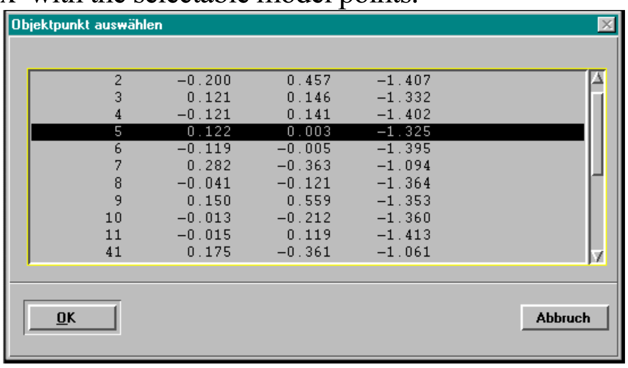


Orientation of the coordinate systems: the third axis must be so chosen that the coordinate system forms a right-handed system.

7.3.2.2 Entering Point Numbers

The point numbers can be entered directly on the keyboard. Also the selection button may be used.

Then appears a dialog box with the selectable model points.



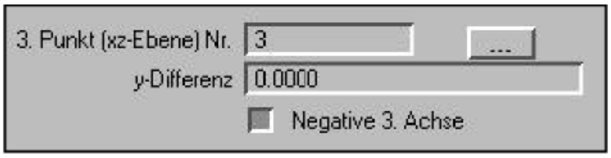
Dialog box for selection of model points

The list shows the contents of the input file. Only the points which are in this list can be used to define the coordinate system.

With *OK,* the points which were selected by mouse are accepted. The *abort* key closes the list without keeping the selection of a point.

As described the second point fixes the direction of X-or Y axis and this point must lie necessarily in the direction of the **positive** axis.

The third point can lie either in negative or positive direction of the third axis. If it is on or near the negative section of the third axis, the switch *Negative 3rd Axis* must be activated.

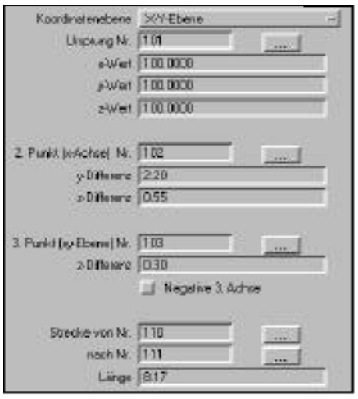


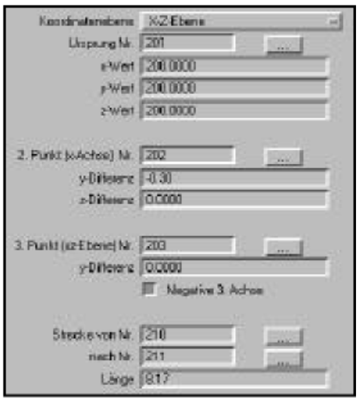
If the 3rd point lies in negative direction of the third axis (here Y axis), the switch *Negatives 3rd Axis* is activated.

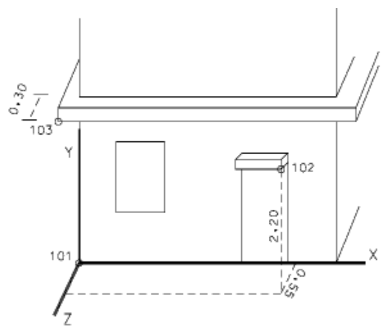
7.3.2.3 Entering Distances of Points from the Coordinate System's Axes

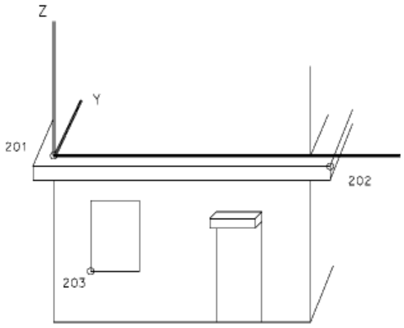
Second and the third point must not lie necessarily exactly on the axes or in the coordinate planes. In the input boxes *Y difference, Z difference*, etc., the respective distance can be entered. It must be paid attention to the sign of these values (+ or –).

If the point is towards the positive axis of coordinates, the difference must be given positively. Otherwise the negative portent is to be chosen.









Examples to the definition of the coordinate systems on the basis of 3 points in the upper example the X Y axes and in the lower example X Z plane fit the building wall.

The coordinate system should be laid in parallel to the building wall. In the first example the point No. 101 (on the lower-left corner) is used as an origin. For definition of the (positive) X axis the corner point is available in the upper-left corner (No. 102). This point lies neither on the identical height of No. 101 nor directly on the façade of the building. Similar is the third point No. 103 which has a distance of 0.30 m to the wall plane.

In the second example shows that the third point lies to a certain amount below the X axis. In this case the check-box *Negatives 3rd Axis* must be switched on.

7.3.2.4 Computational Aid

The button *Calc* leads to a dialog box named *coordinate comparison.* Here distances and coordinate differences from the available object points can be determined very simply. All other explanations for this computational aid are in chapter 9.5 (Editing Additional Observations).

7.3.3 Transformation of Model Points to a New Position

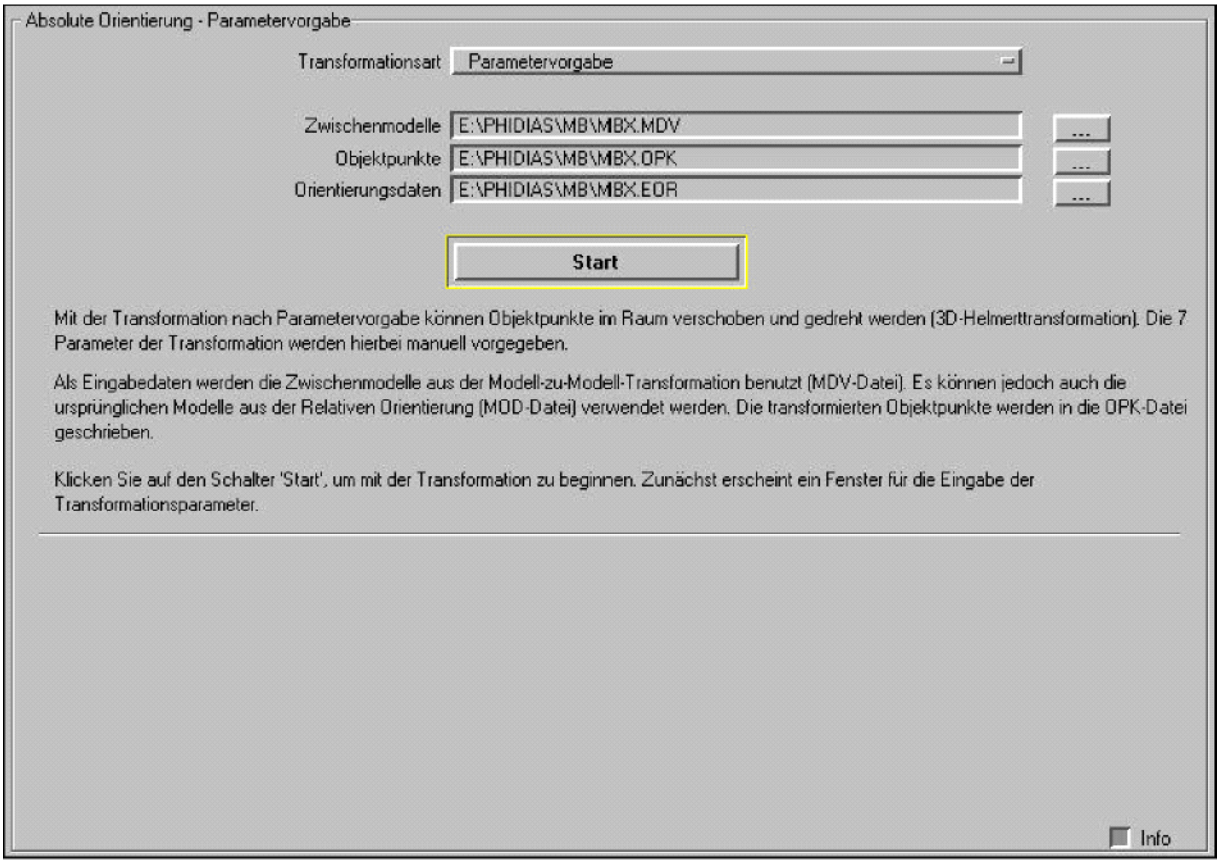
With the button *OK,* the transformation is carried out into a new coordinate system. The points are stored in the result file (here: MBX.O3P), and three points which were used in definition of the coordinate system stand at first lines. The data format of the object points is kept in MBUN (OPK file, see chapter *Data Formats).* At the end a message announces the number of transformed points.

7.4 Absolute Orientations – Default Parameters

Absolute orientation is mathematically based on the model of Helmert transformation (similarity transformation). The spatial Helmert transformation is based on a total of 7 parameters:

- Scale
- Three translations in X, Y and Z
- As well as three rotations around the coordinate axes (Omg, Phi, Kap)

In *"default parameter"* transformation, model points (MDV or MOD file) or object points (OPK file) can be transformed according to given parameters.



At the beginning of the calculation three files must be given:

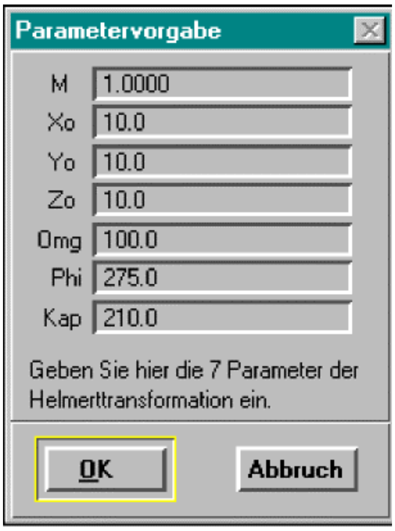
MBX.MDV: the transformed model data from 3-points transformation which are used in model to model transformation (chapter 7.1). The standard name for the file extension is .MDV.

MBX.OPK: in this file the transformation results are stored (the coordinates of the newly stored model points). If this file already exists, the data are appended and there appears a suitable tip. Otherwise a new file is created.

MBX.EOR: the orientation data of the images (locations, rotation) are stored in this file, provided that they are along with the relative orientation.

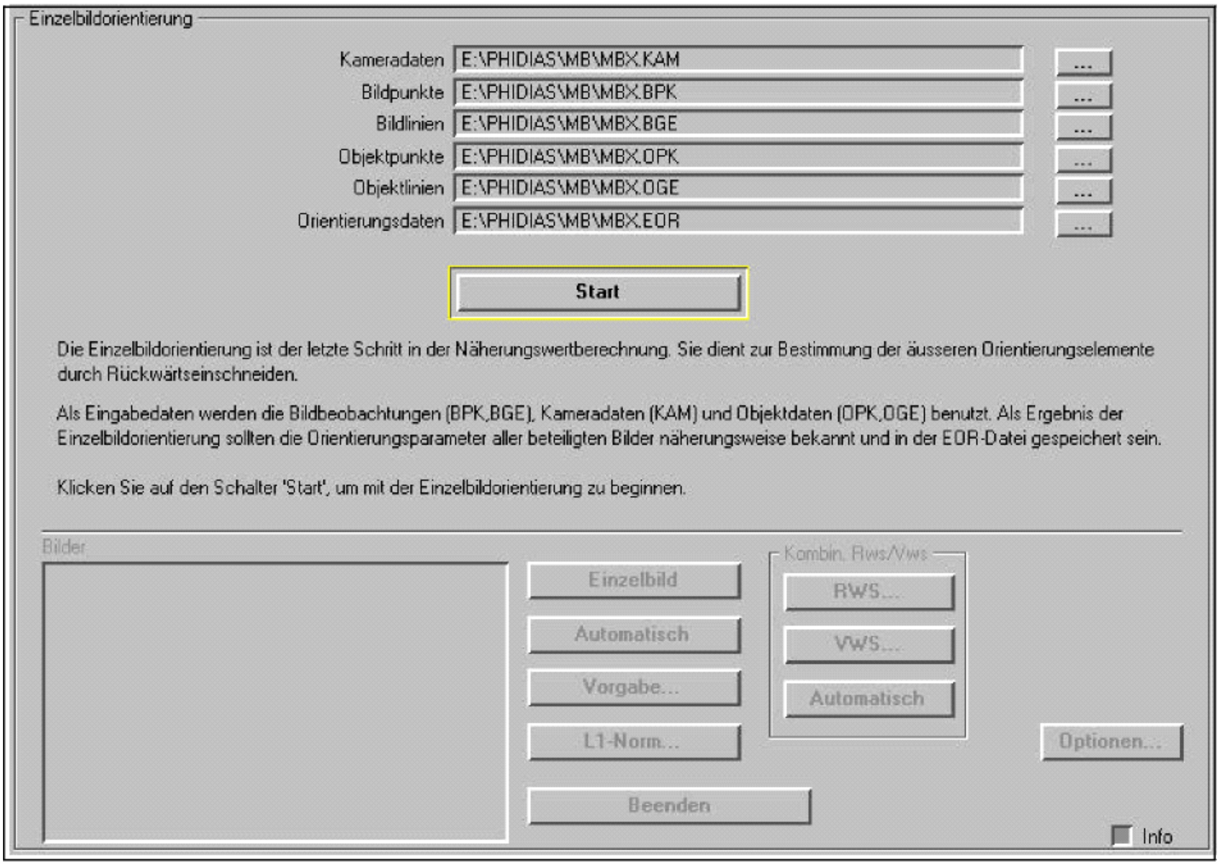
Instead of the MDV file the MOD file from the relative orientation or the OPK file of the object points can be also declared as an input file. Indeed, only the first model is read with former.

After *starting* a dialog box with 7 transformation parameters appears:



Input field of default parameter

8. Frame Orientation



The frame orientation delivers the approximate values for exterior orientation parameters of the images. On this occasion, six files are applied:

MBX.BPK: Measured image coordinates which are read from BPK file.

MBX.BGE: Further measured image straight lines (can be carves) which are admitted as observations.

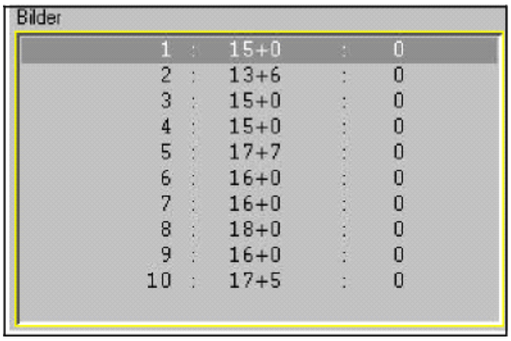
MBX.KAM: Contains the calibration parameters of the camera involved in photography, moreover the specification of some other cameras could be likely found in this file.

MBX.OPK: Object points (control points) coordinates are to be found in OPK file.

MBX.OGE: Similarly the object lines are administered in OGE file.

MBX.EOR: This file contains the results of the frame orientation (exterior orientation) and presents parameters of each image which were taken by a particular camera.

The list of *"Images"* shows all images which are involved in the project.



List of the images whose orientation parameters should be calculated in the progress of frame orientation.

There are three columns in the list above: next to the number of the images (first column) in the second column exists the number of the observations which is given in each case available for the calculation. In most cases these quantities declare the number of points, nevertheless, can be also lines; image. For example No. 2 possibly contains more than 13 image points and 6 image lines which have been measured. In the last column the number of the outliers is displayed and at the beginning all of these amounts are equal to zero.

Now two methods are generally available to the user to carry out the image orientation. Besides, both of these methods are based on some approximate values and the iterative method of bundle adjustment:

Strategy I: the first strategy contains the standard procedure. The approximate values for camera orientations and object data are determined by the sequential realization of relative, absolute and frame orientation. This approach is thoroughly described in chapter 14.

Strategy II: another approach shows the second variant which makes relative and absolute orientation of no use. The image orientation begins with the frame orientation. Then the approximate values are calculated empirically through resection and intersection (see also chapter 8.5.). Determining the approximate value through resection and intersection does make sense especially in case of having redundant control points.

In case of the standard approach (strategy I) there are basically four possibilities:

I. Every image is calculated individually and the program automatically determines the approximate values of the orientation parameters (chapter 8.1).

II. The user gives the approximated orientation parameters manually and the program continues on the orientation process based on these values. (Chapter 8.2)

III. When the frame (exterior) orientation equations are not convergent, the problem can be looked for in image observations (consisting lines and points) using L1 norm. (Chapter 8.3)

IV. This approach is to be automatically carried out for all images (chapter 8.4).

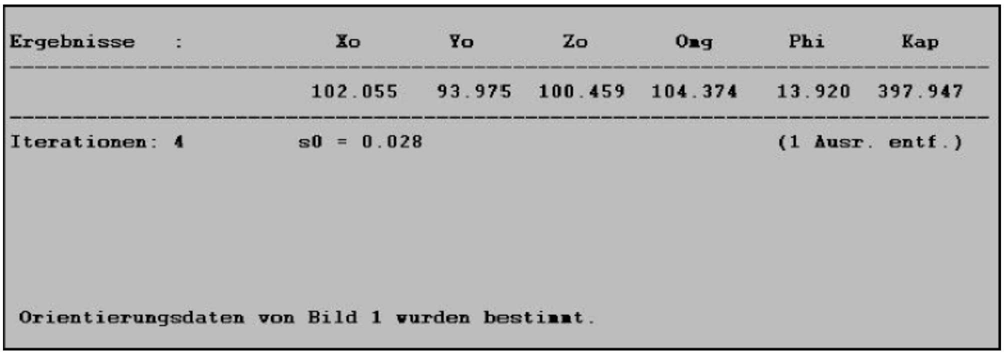
Normally automatic calculation will be used. Especially for difficult cases the user can carry out manual calculation or carry out searching for extremely faulty points.

8.1 Calculation of Single Images with Automatic Determination of Approximate Values

After selecting the desired image from the list of the images by clicking the button *"Frame"* the calculation of a single image starts.

8.1.1 Calculation of Orientation Parameters

At first the program tries to determine the approximate values for 6 unknown orientation parameters (3 coordinates of the projection center and 3 rotations of the image coordinate system). Afterwards the exact values are calculated by adjustment.



Example of the result display of frame orientation

In upper part of the screen the orientation results are indicated. The amounts X0, Y0 and Z0 fix the position of the camera or actually the projection center. The rotations Omega, Phi and Kappa (in gon) called the rotations of the image system which corresponds the object coordinate system and the image system.

Like relative and absolute orientation an outlier test is carried out for frame orientation. If any gross error in the observations (here image point coordinates and if necessary image line parameters) are discovered, the program eliminates the faulty observation.

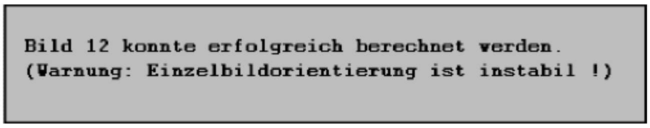
If the number of iteration is very high (greater 20) but the limit amounts are not satisfied and the equations are not convergent you may search the cause of this failure in the following items:

- Dimensions of image frame might have been measured badly or wrongly.
- The involved object data (point coordinates or line parameters) are possibly faulty.
- The geometry of the image rays is unfavorable it means they are not distributed well over the surface of the object. There must be considered more control points at the perspective areas of the image

For avoiding such these difficulties, the image points must be pre-analyzed before measurement.

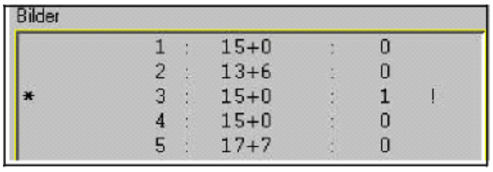
8.1.1.1 Unreliable Results of Calculation

The reliability of calculation is checked after determination of orientation parameters. Unreliable results can be cause of a very wrong measurement or possibly an incorrect point. If an image is doubted to have faulty points or measurements the following warning messages appears:



Warning for unreliable results in frame orientation

All unsteady images are marked in the list with an exclamation mark at the end of the corresponding line.

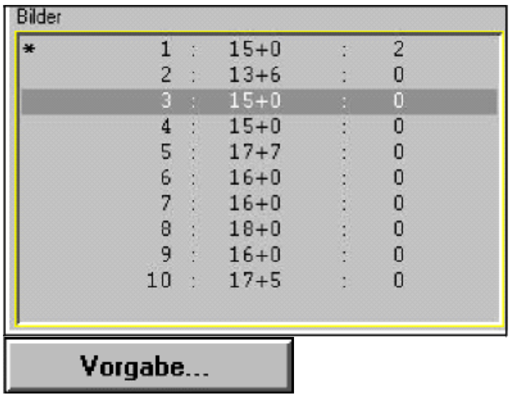


Mark of unsteady orientation results with exclamation mark at the end of each respective line

Unreliable orientation data must be renounced completely, because such images can lead the whole calculation of bundle adjustment to a failure (no convergence). If possibly the bundle adjustment does not succeed, it is recommended to check the unreliability of the images at first and then deactivating the image which is marked with an exclamation mark (chapter 9).

Searching for errors is another alternative to find not only the faulty image measurements, but also the spatial object data (object points or lines) which can be the cause of the failure of the calculation.

8.1.1.2 Markings after Successful Frame Orientation



The above list is according to calculation of an image: the successful line is marked with an asterisk and at the end of each line the number of outliers is stated.

Every successfully calculated and stored image gets a mark at the beginning of the line. In addition, the number of the outliers is announced.

8.1.2 Errors During Frame Orientation

During the calculation of the orientation parameters if any error occurs, a short message informs about the reason of the abortion.

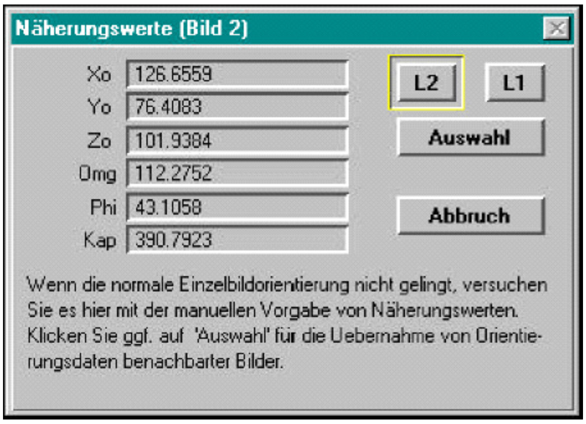
If necessary the user can change the calculation method as an alternative (see chapter 8.6). In this method instead of *adjustment* only the *approximate values* are used before the investigation of extremely gross errors.

8.2 Calculation of Single Images with Manual Approximate Values

For calculations of single images by manual approximate values, first the respective image is selected from the list then the button *"manual"* clicked.

Then the dialog box *"Approximate values"* opens.

By default the last formerly calculated orientation parameters are put down in the fields of this window; the user can carry out some changes over the keyboard.

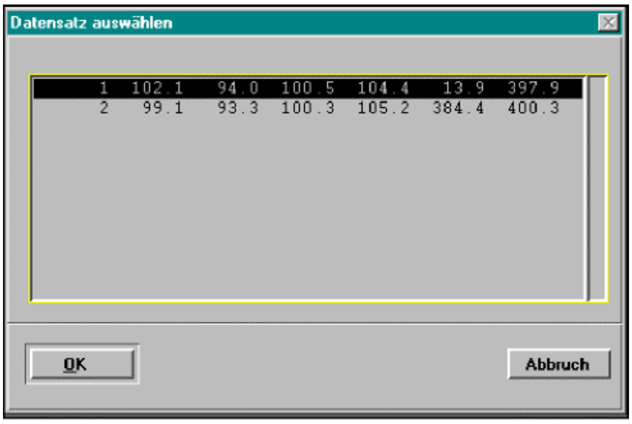


Dialog box for default manual approximate value

8.2.1 Using Orientation Data of Other Images

The manual input of approximate values is necessary primarily if the program obtains no result for an image. The user should try to give plausible approximate values.

The approximate values which were already used for a certain image can be applied again in case of another image. On this occasion click the button *"Select"* to choose the existing approximate values.



List of already used orientation parameters

In a lot of situations the above list is helpful because the data of neighboring images is compatible as approximate values of the new image.

With *"OK"* button the selected record is taken into account and is added to the fields of approximate values. For canceling click on the button "*abort*".

8.2.2 Starting Calculation with Default Values

After respective values are replaced into suitable fields the frame orientation can be begun. The user can choose, whether the L2 norm or the L1 norm should be calculated.

Through the button *"L2"* a usual outlier test along with adjustment is calculated. In principle this is identical to *"frame"* button. Indeed, the program begins the adjustment now with the default data. (See also chapters 8.1.1 to the 8.1.2).

The L1 norm is a special method of the searching for gross errors in the observation. Background information to the L1 norm is to be found under chapter 6.5; in the following chapter the essential points of view of frame orientation are concerned. If this test does not lead to a result the default approximate values can be provided.

8.3 Search for Gross Errors with L1 Norm

Sometimes the program gets no solution with the frame orientation of an image. In these cases the calculation is broken off with a tip *"no inversion"* or "*no minimum*". Because the adjustment is not convergent normal outlier tests are to be applied.

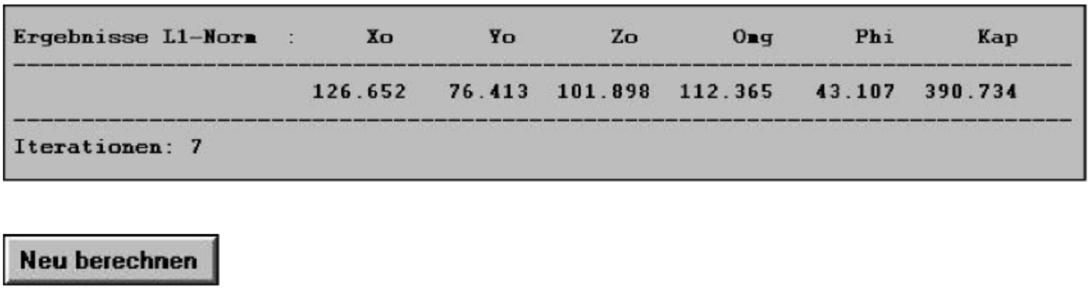
The cause is possibly in an extremely wrong image point. In these situations the L1 norm test can be implemented.

At this time the L1 norm (blunder detection) is applied only on image points not on line observations.

8.3.1 Execute Search for Extreme Errors

Outlier test can be begun by clicking the button *"L1 norm"* after selecting the appropriate image from the list of *"Images"*.

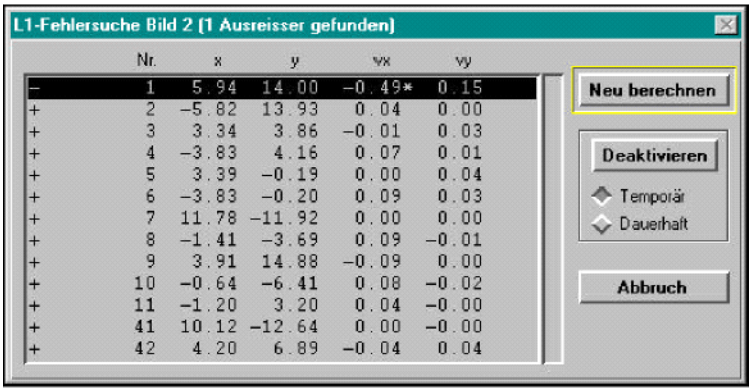
If the calculation leads to a result, the results of the L1-norm are shown in the upper part message window. Since the L1-Norm is used only for the error tracing, these orientation results are however only secondary.



Ergebnisse L1-Norm :	Xo	Yo	Zo	Omg	Phi	Kap
	126.652	76.413	101.898	112.365	43.107	390.734
Iterationen: 7						

Display of the results of L1 calculation

In addition, another dialog box is opened in which the results of the L1-blunder detection are indicated.



L1-Fehlersuche Bild 2 (1 Ausreisser gefunden)

	Nr.	x	y	vx	vy
–	1	5.94	14.00	–0.49*	0.15
+	2	–5.82	13.93	0.04	0.00
+	3	3.34	3.86	–0.01	0.03
+	4	–3.83	4.16	0.07	0.01
+	5	3.39	–0.19	0.00	0.04
+	6	–3.83	–0.20	0.09	0.03
+	7	11.78	–11.92	0.00	0.00
+	8	–1.41	–3.69	0.09	–0.01
+	9	3.91	14.88	–0.09	0.00
+	10	–0.64	–6.41	0.08	–0.02
+	11	–1.20	3.20	0.04	–0.00
+	41	10.12	–12.64	0.00	–0.00
+	42	4.20	6.89	–0.04	0.04

Dialog box with the results of the L1-blunder detection: at the columns of residuals an asterisk appears at each residual which exceeds the limit values, identified beforehand.

Through L1-blunder detection residuals (vx and vy) are determined for every image point and some residuals own value of 0.0. The residuals determine the faulty observations (image points).

A image point whose residual exceeds a certain limit value will be declared in this list. Then the line is marked with a minus sign. The limit value for the judgment whether the coordinate is a faulty one or not, can be adjusted through *"options* (see chapter 8.6).

The user can activate and deactivate the faulty points with '+' and '−' keys from the keyboard. After the execution of L1-norm (blunder detection) and indication of faulty object points, a new calculation should take place again by clicking the button *"New calculate"*. In the new calculation only the object points are involved which own a plus sign in the list. The program carries out a normal model transformation.The L2 norm adjustment is described in chapter 8.1.

The new calculation - i.e. the usual adjustment by method of least squares - must always follow the L1 norm; however there are no errors. The transformation parameters from the L1 norm are not used generally in the absolute orientation for the conversion of the object points into reference system. The L1 norm exclusively functions the role of releasing outliers.

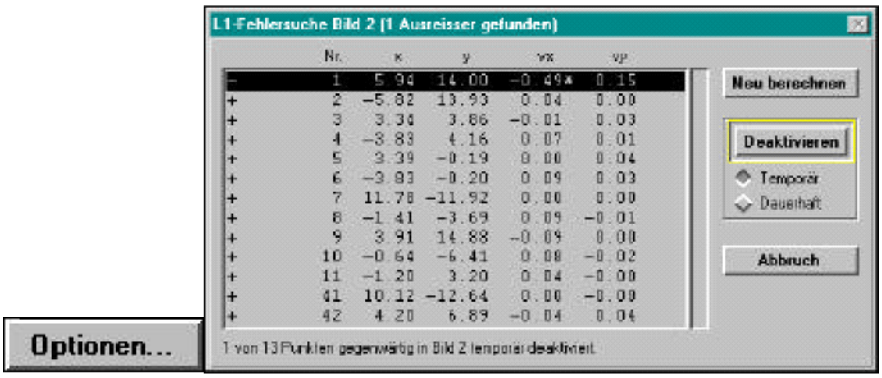
8.3.2 Deactivate Object Points Temporarily or Permanently

The deactivation of the object points (with the minus sign) first has been done by new calculation after L1-norm calculation (see the proceeding chapter). Independently the object points can be deactivated with the button *"Deactivate"* temporarily or permanently.

Temporarily: temporary deactivation signifies that the deactivated points are no longer used during the absolute orientation. If the absolute orientation is quitted and is called once more, the object points are available again.

Permanently: The lasting deactivation marks the respective points in the MOD file as inactive points. This means that the object points are not taken into account in any case that the MOD file is used. If the relative orientation is carried out once more a new MOD file is generated then the deactivation is canceled again. The permanent deactivation endures until the new generation of MOD file.

The deactivation takes place by clicking *"Deactivate"* button, afterward in the lower part of the dialog box is informed about it.



The dialog box *L1-blunder detection* for the temporary deactivation of an object point (here No. 3)

The object points with a minus sign are always deactivated. The deactivation can be cancelled by '+' key. If the L1-blunder detection leads to no result, there remains the test accepted the image and object points.

8.4 Automatic Execution of Frame Orientation

In most cases the frame orientation can be carried out for all images automatically. Then the program carries out all necessary actions.

8.4.1 Starting Automatic Calculation

The automatic calculation begins after clicking the button *“Automatic”*. During the calculations the user is informed constantly about the fact which image is just processed.

After complementation of automatic frame orientation, the program informs about the number of successful calculated images:

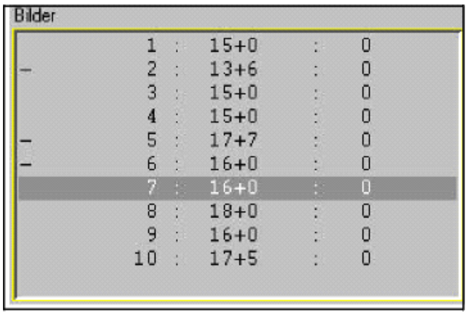
Message according to automatic calculation

8.4.2 Order of Calculations

The images are processed in the order as they stand in the list. Because all the images are computed independently, so the order is not important at all.

8.4.3 Excluding Images from Calculation

Before starting of automatic orientation, individual images can be excluded directly.

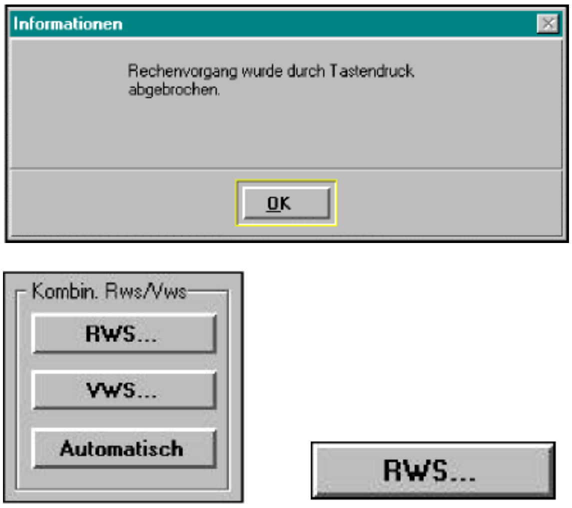


Images can be excluded by plus key ‘+’ or the space bar.

With minus, plus and space bar keys the appropriate images become inactive or active. Then the respective lines get an appropriate mark. All images with a minus sign are not used in automatic calculation cycle.

8.4.4 Abort Automatic Frame Orientation

After the beginning of the automatic calculation pressing of any key leads to the program to abortion, so the user is informed by a suitable message:



Abortion message of automatic frame orientation

For continuation of the program click the *OK* button.

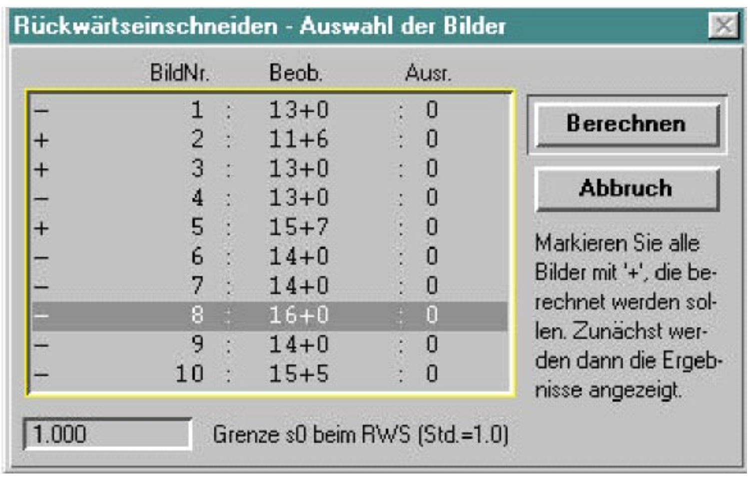
8.5 Combined Resection and Intersection

It was described at the beginning of chapter 8, how basically approximate values can be determined. As an alternative to the standard procedure a *combined resection and intersection* can be carried out. Because relative and absolute orientations are not used in this approach, this procedure is basically quicker. However enough control points should exist, in order to get reliable results. If the project consists of several images with only few control points, the standard procedure with relative, absolute and usual frame orientation is more practical.

The basic principle of the following procedure is based on the fact that alternating resection and intersection is implemented. With the resection the orientation data of camera position and camera rotations and with the intersection the data of the new points and new lines are determined. The continuance of approximate values for orientation data and object data goes on step by step.

8.5.1 Resection

The resection stands generally at the beginning of a calculation cycle. It is called *resection.*



The *dialog box of resection* is opened for the selection of images.

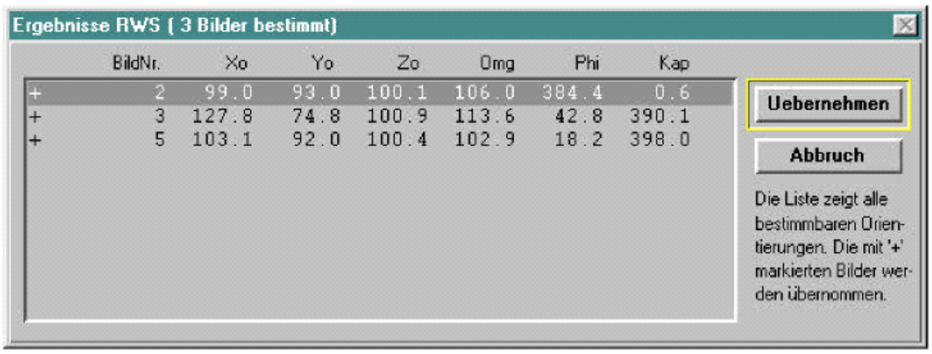
Enforcement of resection:

In this dialog box all images of the project are listed. Only those images with a '+' mark are taken into account and however the user can change the mark accordingly.

Only images with an enough number of observations will be selected. This principle has the first priority which has to be met. The sufficient number usually is at least 6-8 object points or linear observations. If only few object data (less than 5) exist, the user should activate only a few images and an intersection in-between (chapter 8.5.2).

The limit value s_0 indicates whether a calculation result is accepted or not. Satisfactory results are released only if this value (standard deviation s_0) suits the certain limit amount. The demands can be determined by changing the limit value.

A frame orientation or resection is carried out for all images which are marked with a plus sign by clicking the button *"Calculate"*. The result of this process is indicated in another dialog box.



Ergebnisse des Rückwärtseinschneidens

All images which could be calculated appear in the list along with their orientation data. If the list is chosen shorter than originally, the resection might not be carried out for one or several images successfully.

The orientation data (camera position and rotations) can be checked for plausibility once more at this time. With the button *"accept"* the user accepts the results of resection and if necessary before the calculation single images can be excluded by typing '–' on the keyboard.

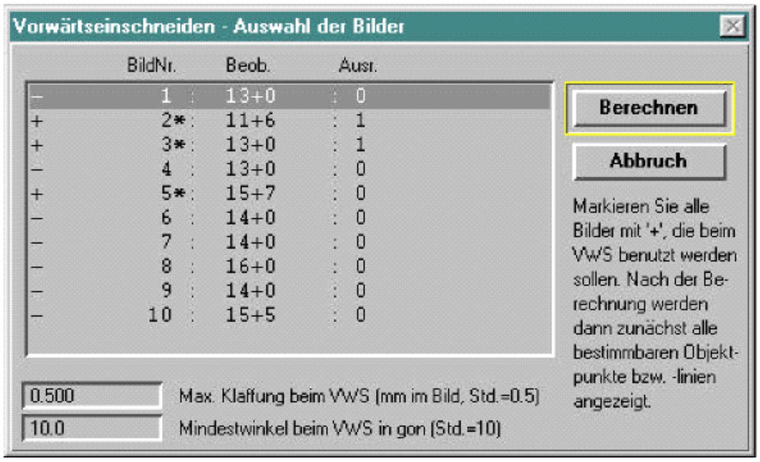
The orientation data are stored after finishing the program *"frame orientation"*. Afterwards the calculated images are marked by an asterisk in the list of images.

8.5.2 Intersection

In calculation step *intersection* further object points, i.e. new points, or new object lines will be calculated. Moreover the button *Intersection* is clicked.

Preliminary remark: Lines were treated as observations in orientation. This program tries to get approximate values for spatial straight lines. Usually the ending and beginning pints of straight lines are not measured at the site of photography. Therefore, only the intersection can help the user to extract the parameters of straight lines.

After the resection a dialog box appears and the images, which should be involved in this intersection, are to be selected here in this dialog box.

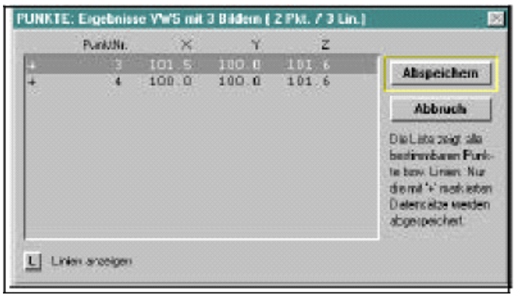


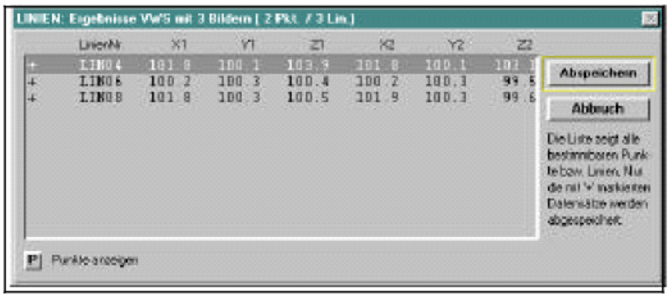
Dialog box for the intersection. The asterisk behind the image number signifies that the orientation parameters are already calculated.

The plus or minus marks next to every line has the same importance as it has in resection. We can activate the images with which the orientation data exists. The marks next to the number of the image (asterisk) mean which image has orientation parameters.

The limit values for the*" maximum residual"* and the *"least angle"* can be adjusted when required. A single object point is calculated only if the rays fulfill these limits (see also chapter 8.6). For lines only the *"least angle"* limit is taken into account.

If the key *"calculate"* is clicked, the program does the intersection for all computable points or lines. The result of this process is indicated afterwards.





At first all object points and if necessary the object lines which could be determined by intersection are indicated. In this example 2 points and 3 lines could be calculated. With the button *"lines register"* or *"show points",* the display is switched.

At this time the user can still exclude some points or lines. Therefore the respective line will get a minus'-'sign. By clicking the button *"Save"* only the images with a plus mark will be stored.

Against to the orientation data the new coordinates of points are stored directly in the OPK file and the object lines accordingly in the OGE file. For eliminating the stored points the user must edit the two mentioned files explicitly through and editor program (chapter 9). Accordingly the number of the points or lines is updated in the list of the images.

8.5.3 Automatic Resections and Intersections

The mutual resection and intersection can be done automatically. For this the button *"automatic"* is clicked in order to execute combined resection/intersection processes.

After completion of resection and intersection the object points and lines are stored in OPK and OGE files respectively. Before storing the mentioned files the user will be ask what action the program should take:

Confirmation inquiry with the automatic resection/intersection

If necessary the files EOR, OPK and OGE which were changed, can be edited manually and restore their first state simply.

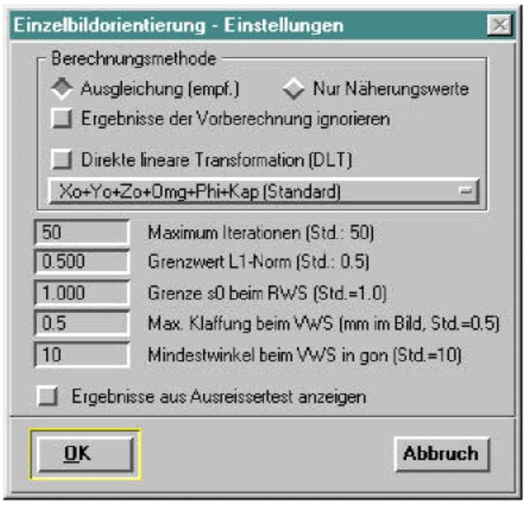
By clicking *"OK"* button automatic calculation begins. Then the program carries out alternately resections and intersections, until all requested parameters are determined. At the end of calculation the user is informed about how many orientations or images and object points or lines were used. In addition, the image list is also updated.

Message according to the automatic calculation

8.6 Settings for Frame Orientation

The button *"Options"* leads the user to a dialog box in which there are different settings for frame orientation.

Then the dialog box *"Settings"* provides different fields in which the user can influence and make some changes.



Settings of frame orientation

8.6.1 Calculation Method

8.6.1.1 With or Without Adjustment

Normally the frame orientation is done on the basis of least square adjustment. The adjustment calculation is the more precise and more reliable method. In this method the data material is investigated for gross errors. The approximate solution determines only the approximate values of the orientation parameters; therefore, the calculation is considerably quicker. Rarely wouldn't be successful the calculation.

8.6.1.2 Ignoring the Results of the Pre-Calculation

If relative and absolute orientation were carried out successfully before the frame orientation, the first approximate values already exist. Normally these approximate values are very good and should be used. The pre-calculation results (relative and absolute orientation) can be ignored by activating the appropriate switch.

8.6.1.3 Polynomials of the Parameters

The spatial resection underlies as a mathematical model of frame orientation. As a purpose 6 parameters of exterior orientation are calculated (three position coordinates of exposure center and three rotations of image coordinate system). The parameters of the interior orientation (f, X_0, Y_0) are also treated in this context. Even if the camera data are introduced only as estimated values, usually this is sufficient. Because single frame orientation is used only for the determination of approximate values.

In addition to this standard configuration it is possible to calculate simultaneously the parameters of interior orientation (camera data). So altogether there are the following parameter sets:

1. only exterior orientation, standard *($X_0+Y_0+Z_0+\omega+\varphi+\kappa$)*
2. in addition, camera constant (f = c) *($X_0+Y_0+Z_0+\omega+\varphi+\kappa+c$)*
3. in addition, camera constant and X_0 ,Y_0 *($X_0+Y_0+Z_0+\omega+\varphi+\kappa+c+x_h+y_h$)*
4. in addition, camera constant, principal point and *distortion ($X_0+Y_0+Z_0+\omega+\varphi+\kappa+c+x_h+y_h+A_1+A_2$)*

If the frame orientation of images is calculated for extended parameters the result display considers all of them accordingly.

Ergebnisse :	Xo	Yo	Zo	Omg	Phi	Kap
	102.183	94.121	100.376	104.745	14.962	397.965
c,xh,yh :	34.463	0.318	-0.317			
Iterationen: 3	s0 = 0.026				(0 Ausr. entf.)	

Result display with extended polynomials, here with camera constant (f = c) and X_0,Y_0 coordinates.

The data of the interior orientation (c, x_h, y_h, A_1, A_2) cannot be stored. They are just used primarily, for plausibility check of the camera parameters.

In this context it is to be followed that the object data are suitable after arrangement for the parameter extension. Above all if the distortion parameters should be added, at least 10 points should be available according to experience. If the object data lies in a plane, the determination of the camera parameters can be very inexact or be totally impossible.

8.6.1.4 Direct Linear Transformation (DLT)

The direct linear transformation declares an alternative modeling of the frame orientation. Contrary to the standard procedure (exterior orientation and camera parameter) 11 linear parameters are used with DLT. The advantage lies in the fact that no approximate values are needed through this method for beginning. Indeed, at least 6 known object points or lines must also exist.

☐ Direkte lineare Transformation (DLT)

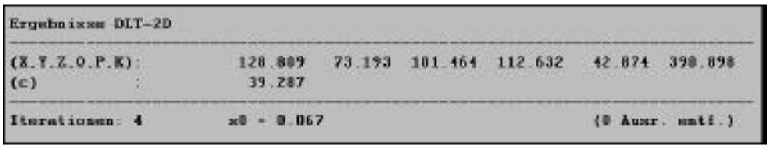
If the DLT check box is activated, the DLT parameters are calculated by the program. However, for issuing the result the 11 parameters of DLT are converted into the usual parameters of the exterior and interior orientation because these are better interpretable. Is to be noticed that the whether the object, the points and lines lie in a plane (2D) or they form a 3-dimensional object. In two-dimensional case the DLT parameters decrease to 8. The program examines which case is at hand.

1. Case: 3D

Ergebnisse DLT-3D						
(X.Y.Z.O.P.K):	6.233	-14.148	4.028	118.959	2.394	399.150
(c.x.y.m.s) :	28.368	0.057	0.036	1.001281	0.000461	
Iterationen: 2	s0 = 0.016				(0 Ausr. entf.)	

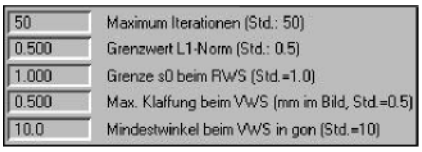
If the object data are distributed in three dimensions, besides the 6 orientation parameters the camera constant and the principal point can be calculated back. Moreover, a scale (m) and a shear constant (s) are given for reasons of consistency.

2. Case: 2D



If the object data form a plane in the space, only the camera constant can additionally be determined. Generally the results are less reliable for c than in the 3D case.

8.6.2 Limit Values



By change of the following limit values the continuation or quit of the program will be determined i.e. in some cases these limits cause the program to be stopped and in other cases they cause the program to continue.

Maximum number of iteration: the single adjustment processes run off iteratively and after few rounds the calculation comes to a convergence. If the program comes to no result within the maximum number of iteration, then the computation is broken off.

Limit value of L1 norm: the L1 norm follows a special procedure in searching for gross errors in the observations. As a result of frame orientation the correction values or residuals of the image coordinates are indicated (see chapter 8.3). These residuals are given in millimeter unit are pretended faulty if they exceed the limit value determined here. The limit value must be adjusted on the user's experiences about project.

Maximum standard deviation s_0 at the resection: in every adjustment the standard deviation s0 is a goodness criterion of the calculation. The smaller this value is, the better is the result. The limit value determined here plays a role in combined resections and intersections especially if the image orientation parameters are determined by resection. The result is only accepted if the standard deviation remains under the determined limit value.

Maximum gap at the intersection: Like the standard deviation s_0 the maximum residual distance - as well as the following least angles – is important with the combined resection/intersection. Only if the maximum residual distance of an image ray does not exceed the limit value over the calculation of new object points by intersection, a point is know as a computable one. The residual distance is the shortest distance between the skew image rays. So that the value is independent on the object size. The maximum residual distance becomes in the unit of the image coordinates mm.

Minimum angles at the intersection: the second criterion that must be considered with the calculation of the object data is this limit value. This limit value should be lower than 10 gon**.** Only in this case the results can be considered reliable. The minimum angle should prevent together with the maximum residual distance that object points or lines with completely implausible spatial position are calculated. The minimum angle also applies to the intersection of lines, which are cuts of planes in space. This planes in space must not form a too sharp angle, so that the resulting straight line is fairly reliable.

8.6.3 Display Results of the Outlier Test

By clicking the button *"results from outliers test"* the program indicates the results of outliers test.

Display of the results of the outliers test

By the button *"indicate lines"* or *"indicate points"* the user can switch between the observation.

In this dialog box the test dimensions as well as the residuals are shown for every image. For image points these residuals are Tx and Ty as well as vx and vy for lines the dimensions Ta and Tb (a and b are the parameters of the image lines) and v1 and v2. The "auxiliary residuals" v1 and v2 indicate the residual distances given by the intersections of the image rays through the end points of the image line, with the corresponding lines in space. These residual distances – as vx and vy – converted into the image system are easier to interpret than the direct residuals va and vb. If a test statistics exceeds the limit value To, there is most probably a blunder and the according value will be marked by an asterisk. The limit value To depends on the current redundancy of the single frame orientation, thus from the number of corresponding image and object data and is given in the title line.

The observation with a failure in outlier test is marked a minus sign. The minus sign signifies an inactivation for the next new calculation. The new calculation will start by clicking the button *"new.* Basically one should repeat the new calculation as long as no more errors are found. However the user can deactivate several observations manually with the minus key, but normally over an iteration only one point (or a line) which has the biggest error is eliminated. If the button *"do not register results from outliers test"* is set active, the program carries out the removal of the gross errors step by step automatically.

By clicking the button *Take over* the frame orientation is accepted and is accepted. Then the dialog box is closed.

Eliminating image points and image lines can be done temporarily or permanently. Execution of this process is described in chapter 8.3 in detail.

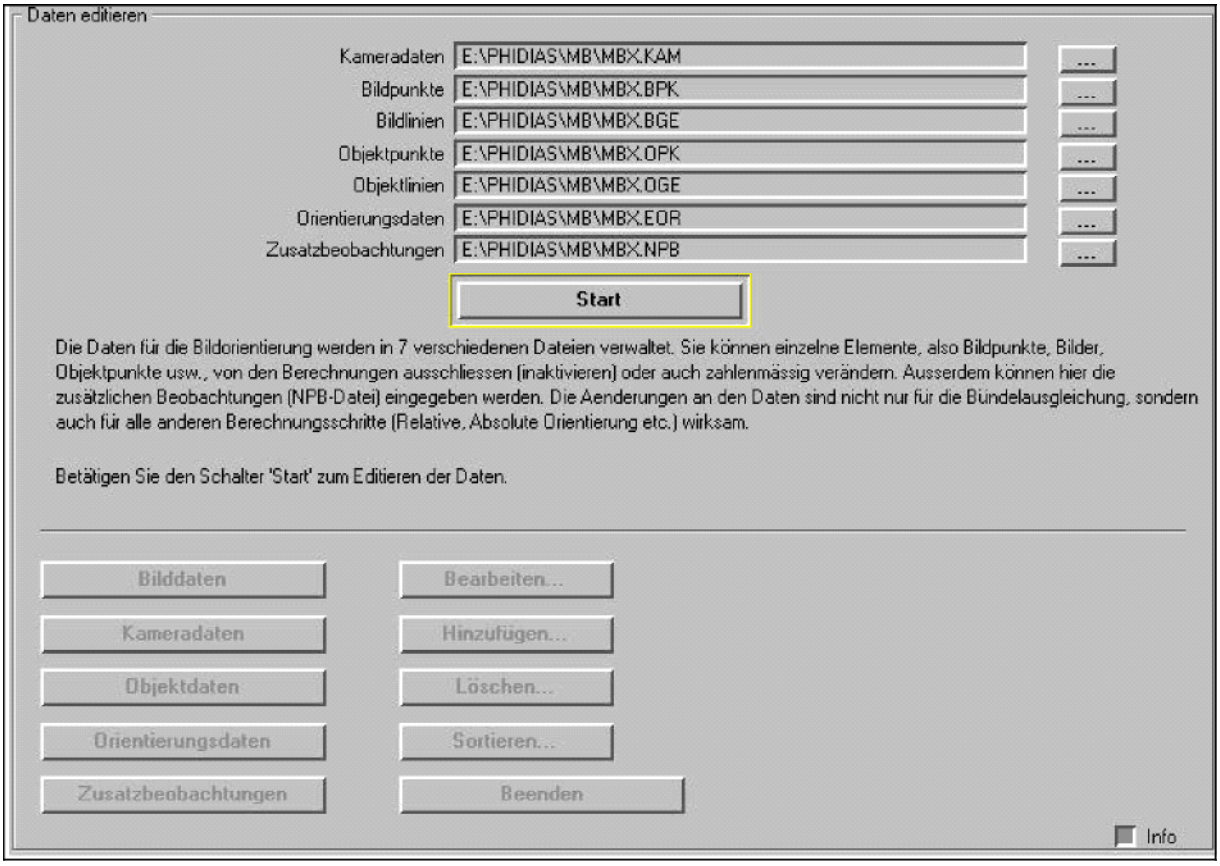
8.7 Finishing Frame Orientation

The frame orientation will be finished by clicking the button *"Finish"*. The a message appears which ask the user whether to save the results or not?

Dialog for finishing frame orientation

Only by clicking the *Save* button the results will be saved for the further orientation process.

9. Edit Data



Before the execution of bundle adjustment (chapter 10) the input data should be edited in a lot of aspects. On this occasion the contents of the following files are to be edited.

MBX.BPK: the file which contains image coordinates of measured points.

MBX.BGE: the file which contains the image lines; if they are available.

MBX.KAM: the file which contains calibration parameters of the camera.

MBX.OPK: the file which contains the coordinates of the surveyed object points.

MBX.OGE: the file which contains straight object lines, if they are available.

MBX.EOR: the file which contains the approximate values of the orientation parameters.

MBX.NPB: the file which contains non-photogrammetric observations. This file generally is empty at the beginning. Here are defined, besides the image coordinates, further observations like distance measurements, coordinate differences, etc.

5 data groups can be indicated with the accompanying buttons. At the beginning the last data which were processed are indicated. In order to see the object point coordinates, click on the button *Object points*.

With *Edit Data* individual data records can be added or deleted as well. (Exception: the data of image points can be modified only neither adding and nor deleting). In addition, the data rows can be sorted according to increasing up numbers. The user can click on the button *"Add"* to add new records of data in appropriate fields.

9.1 Editing Image Data

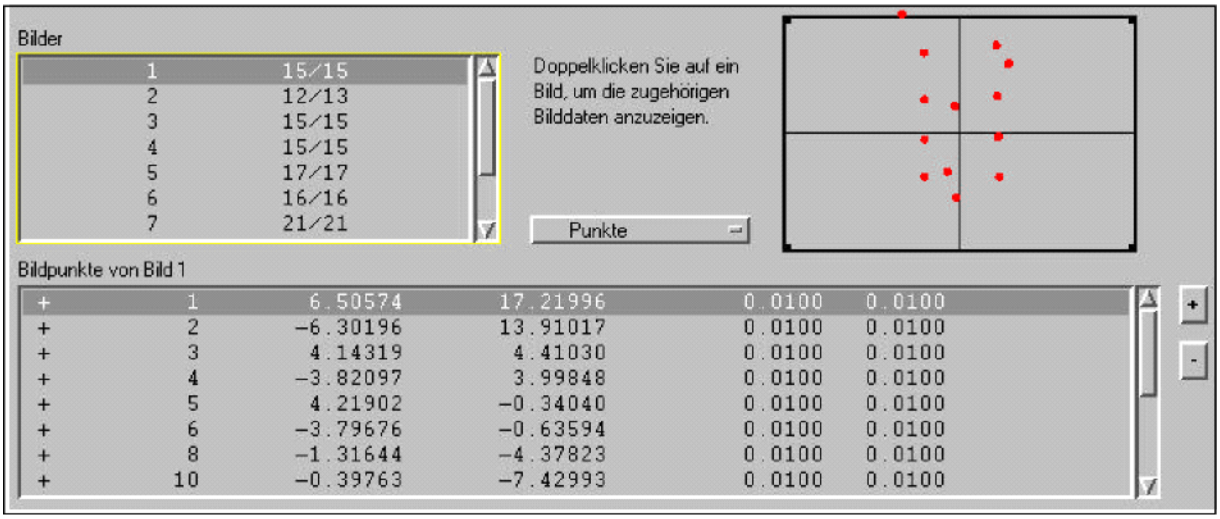
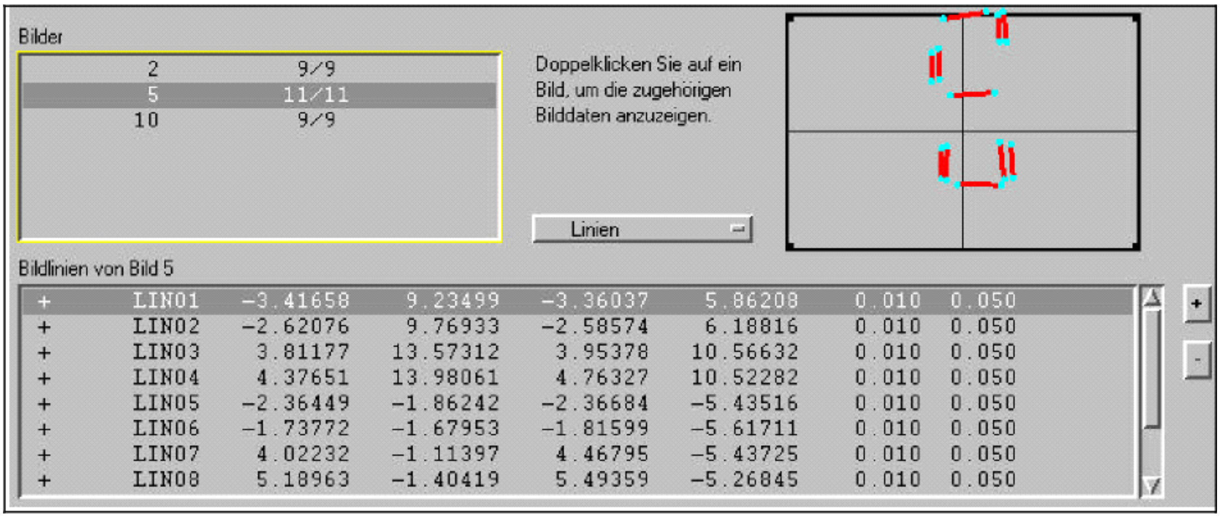


Image data can be image points as well as image lines and the program switches between these two different data types by an appropriate button.

The upper list shows all images and the number of the points or lines which were measured in each image. The ratio 15/15 signifies that a total of 15 points or lines exist in that image (here number 1) and all these points are active. On the other hand the ratio 12/13 means there are 13 points in image number 2 and 12 of these points are active.



By double clicking (or pressing enter key) on the name of the image the observations of that particular image are brought in the list *"images"*. All measurements of the selected image are within the image coordinate system thus the units are in millimeter mm. The weights of the observations are fixed by the standard deviation in the bundle adjustment. In most cases the available default settings can be considered.

The image observations are normally marked with a plus sign at the beginning of the respective line. This signifies that the point or the line is active and takes part in the bundle adjustment. In the process of orientation calculations only the active observations are taken into consideration. The status can be changed either with the plus key or the minus keys of the keyboard.

The deactivation of whole images affects only the orientation data (chapter 9.4).

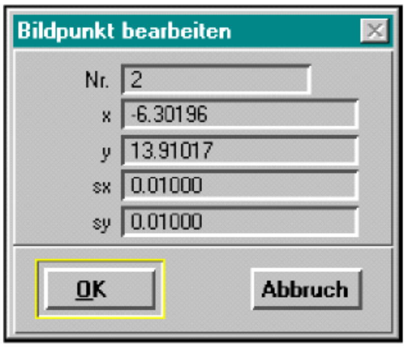
At the above window there is a sketch which shows the relative status of points or lines measured in the image plane. Through this the user obtains an overview about the basic arrangement of the observations and can analyze qualitative positions of the measured points. Every image point or line is made visible by a red bold dots or red bold line. On this occasion, the different colors have the following meanings:

- Red: Observation is active.
- Yellow: Observation is inactive.
- Green: Current observation.

It is to be followed that in each image at least 3 image points or alternatively 6 image lines must be available for bundle adjustment generally in each image at least 6-8 points are used, so that reliable results are achieved. In the bundle adjustment all images which show less than the named least number are automatically excluded.

9.1.1 Working on Image Data

The data of an image point or a line should be edited, so click the button *"Treatment"*. A dialog box appears in which the values can be changed.



Dialogfeld zum Bearbeiten der Bild-punkte bzw. Bildlinien

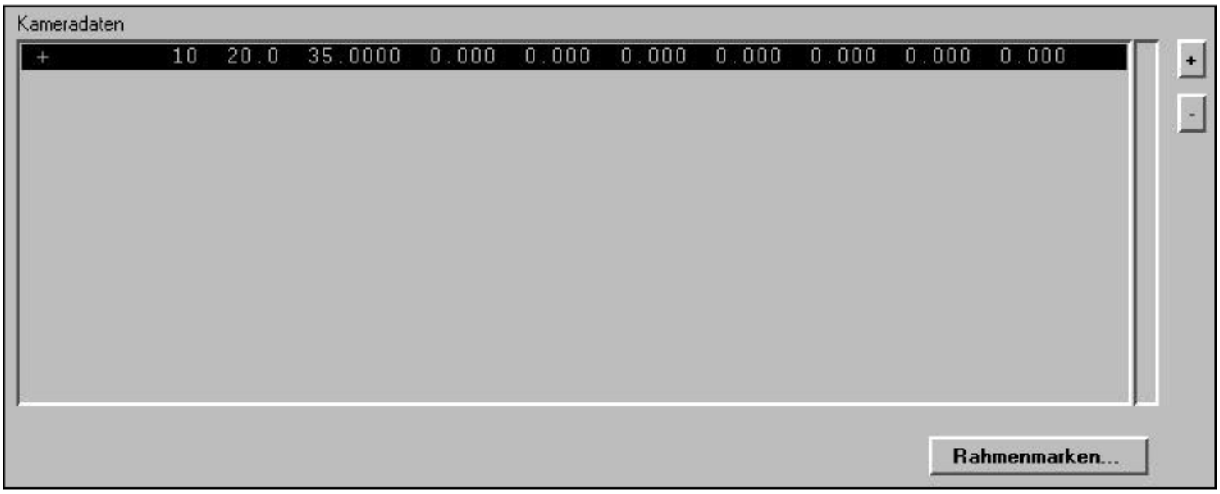
9.1.2 Sorting Data for an Image

The observations of an image are sorted by clicking the button *"sort"*. After clicking the sort button according to number of the images they will be sorted. Then the sorted image are shown in *Image points* or *Image lines* window. Before assortment a confirmation inquiry appears.

Confirmation inquiry before assortment

By clicking "*Yes*" button the new order is set to the images. If the assortment didn't take place a relevant massage appears on the screen.

9.2 Editing Camera Data



While selecting the button *Camera data* the records of the available cameras are indicated on the screen.

All photographs which were taken by the same camera will use the same calibration data for interior orientation.

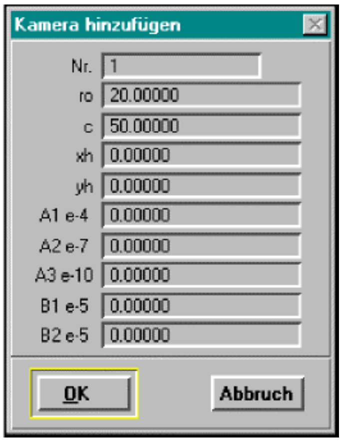
The parameters which describe the interior orientation of a camera are in detail:

c: Camera constant (the focal length)
x_h, y_h: Coordinates of the principal point
A_1, A_2, A_3: Coefficients of the radial-symmetrical distortion
B_1, B_2: Coefficients of the tangential-asymmetric distortion
r_0: Zero-crossover of the curve of distortion

The focal length and the coordinates of the principal point as well as the place of the zero crossover are declared in millimeter mm .

9.2.1 Changing and Deleting Camera Data

Editing the camera data is done like the treatment towards the image data (see also chapter 9.1). In addition, here the user can enter even further camera parameters. A dialog box with the text fields is opened by clicking the button *"Add"* for the camera data.



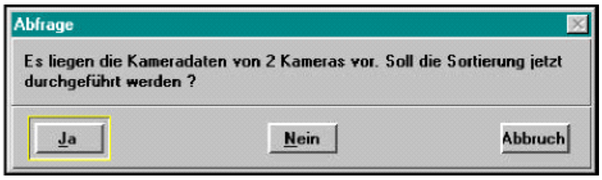
Dialog box for inputting the new camera records

Varianten der Rahmenmarkenspezifikation

With the button *"Delete"* records are removed. After entering the camera calibration parameters click *OK* button to store and close the dialog box.

9.2.2 Sorting Camera Data

The assortment of the camera data can be done by the *sort* button. Then the following inquiry appears *"Yes"*. By clicking yes button over this question the camera data will be sorted.



Sorting question

9.2.3 Editing Camera Data

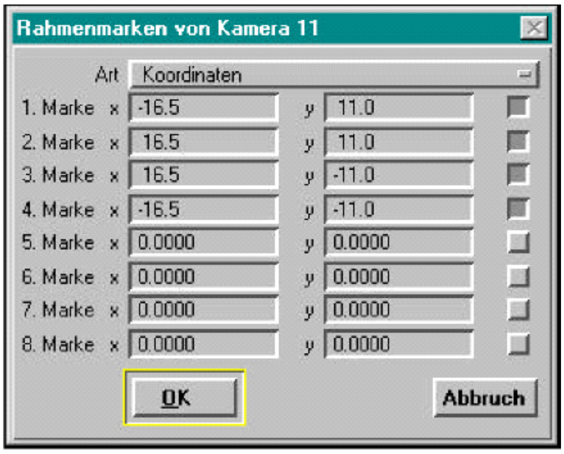
The camera data transforms the pixel coordinates of image points to the coordinate system of the image. In most cases the principal point does not coincide with the intersection of the lines between side fiducial marks. There are different brands of data which concerns this transformation. For selecting the types of calibration data click on the button *"fiducial marks"*.

Generally three types of camera marks exist:

- Coordinates of 8 single
- Réseau data
- Regular réseau

9.2.3.1 Fiducial Mark Definition by Coordinates

There are 8 standard marks within an image called fiducial marks. Therefore in this dialog box 8 coordinates can be entered in which 4 marks are for corner fiducials and four of them are side fiducials. Usually the coordinates of side fiducials are considered in the following fields.

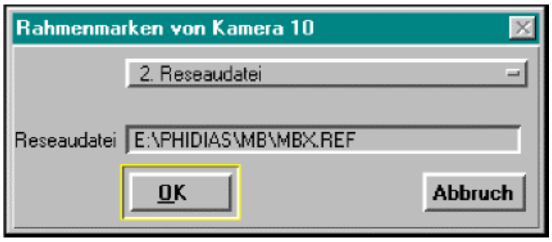


Dialog box for inputting coordinates of fiducial marks. In case of not having such coordinates all fields are dedicated a zero value.

There is an activation box in front of each coordinate pair. Check this box to have the respective fiducial mark activated.

9.2.3.2 Fiducial Mark Definition by Réseau Data

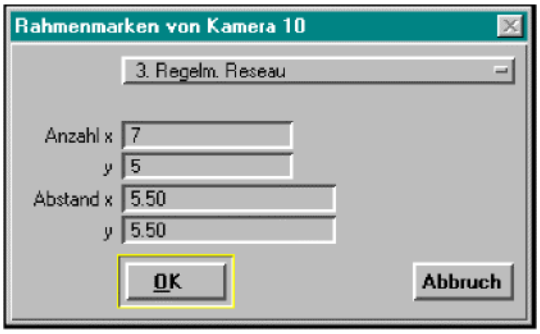
If option *"Réseau data"* was selected, a field appears for inputting of the file name. The name of the réseau data has a standard extension called REF (réseau file).



Fiducial mark definition by réseau data

9.2.3.3 Fiducial Mark Definition by Regular Réseau Grid

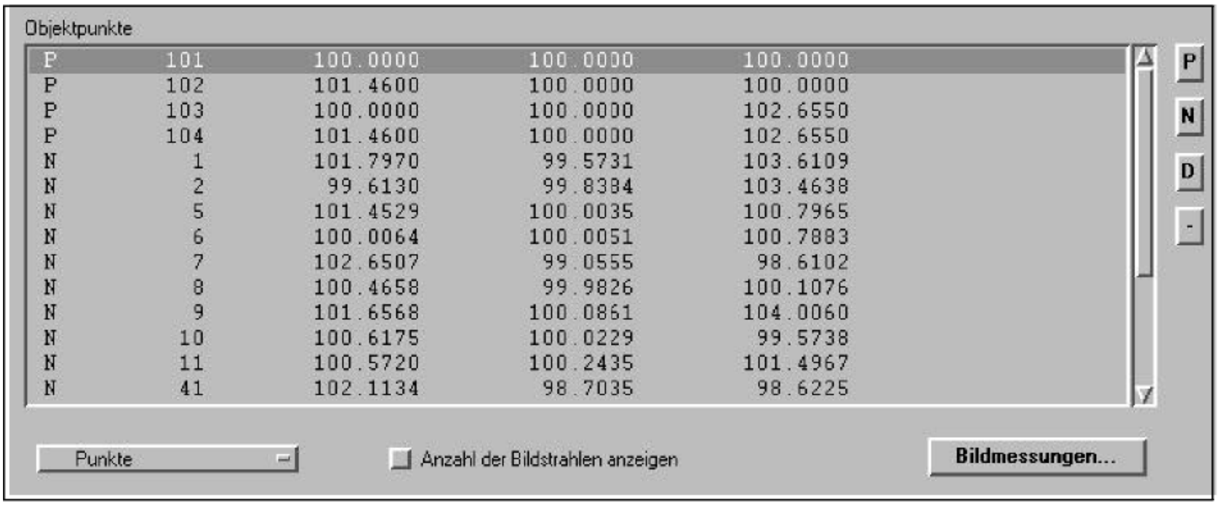
The third option is used for cameras with a réseau plate. The réseau coordinates are fixed by entering the X and Y distance intervals of regular réseau and also the dimension of the réseau grid.

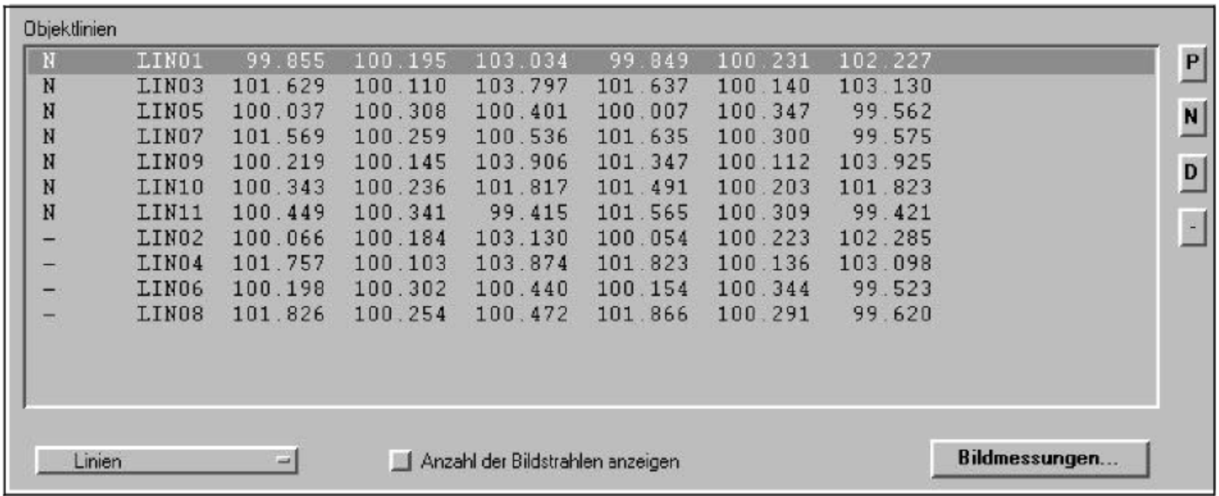


Definition of a regular réseau

Generally one of three named definitions should be applied. The option *none* is compatible for rectification only in that case the camera data can be ignored.

9.3 Editing Object Data



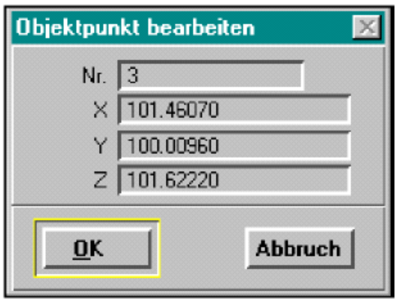


As well as image data, the object data includes points and lines. For changing the display of data type from image data to object data click the appropriate button *"points / lines"*.

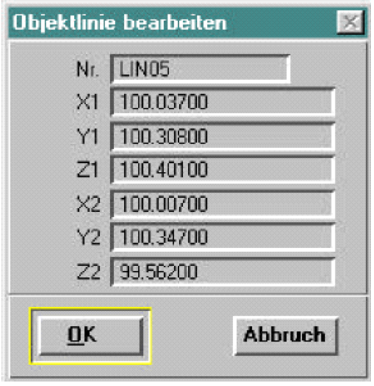
In addition, there stands a button *"number of the image rays"* which is not always active at beginning. By clicking this button the number of active image rays is determined by a message. With bigger projects the process can last a little longer; then if necessary the message "Determining image rays ..." is indicated.

9.3.1 Adding and Deleting Object Data

Editing the object data goes in similar way like the image data.



Dialogbox zum Bearbeiten von Objekt-punkten bzw. -linien



The object points and object lines are marked in special way, through these signs and letters next to each point on one hand the user is informed that which point is active and passive, on the other hand it's clear what function is applied by the program towards the respective point.

- **P:** control point / line, i.e. the parameters are known and remain steady.
- **N:** New point / line, i.e. the parameters are unknown and should be determined.
- **D:** datum point / line for the storage with the free network adjustment
- –: The point or the line is inactive.

The status of an object point or a line is changed by clicking of the suitable key. Thus a point with P (control point) key becomes a new point by clicking the N key. Alternatively the suitable buttons can be used toward other points in the list.

9.3.2 Sorting Object Data

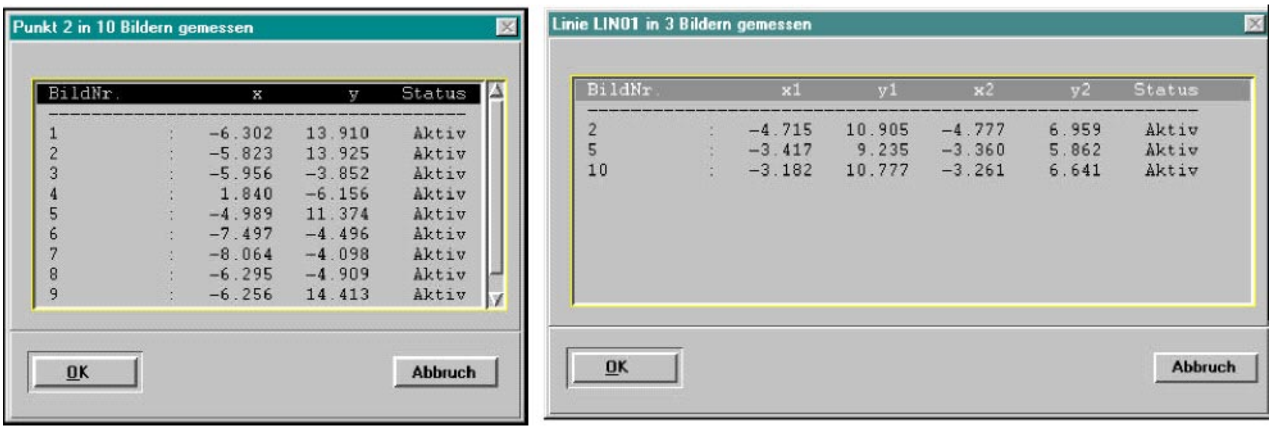
The assortment takes on the status of the object points or lines which was described above. If the assortment is carried out, the records are sorted in groups: then first control points / control lines (P), the new points / new lines (N) afterwards - if available - the datum points / datum lines (D) and, at the end, if necessary all inactivated records come after.

By clicking the button *"sort"* the confirmation inquiry appears at first.

Confirmation inquiry of assortment of e.g. object points

9.3.3 Display Image Measurements

For each object point or every object line the image measurements are indicated by clicking on the button *"Image measurements"*. Then the program determines all images in which this point or this line is measured. Image measurements are shown in a special dialog box.



Display image measurements, here for point no. 2 and line 01.

Every image which contains point or line is dedicated a line in this list and the measured image coordinates of ending and starting points of lines (x and y) are indicated. In addition, activation status is indicated at the end of each line. There is no applicable function in this dialog box and by clicking *"OK"* or *"Abort"* button it will be closed.

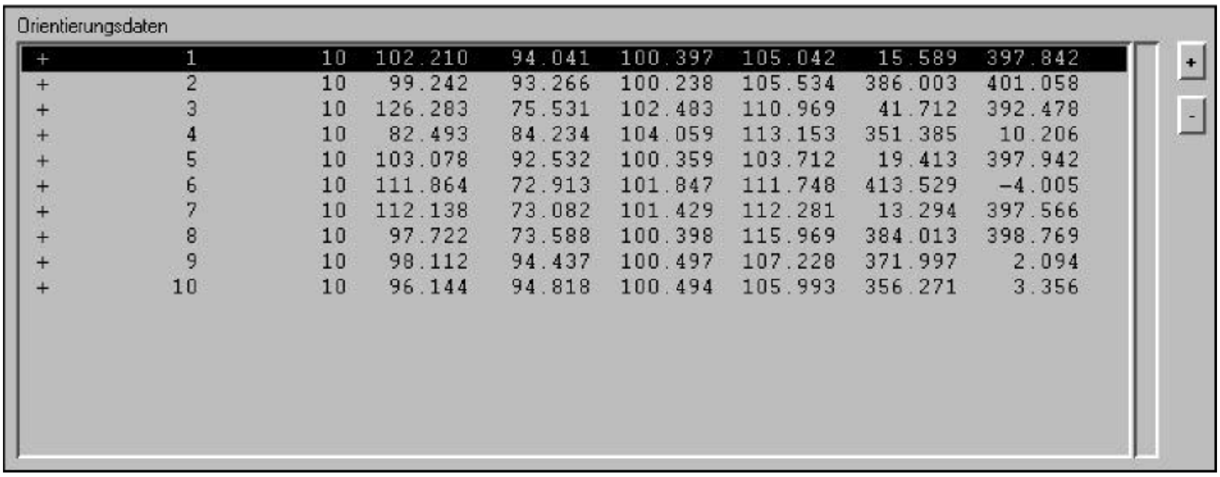
9.3.4 Treatment of Control and Datum Points or Lines (P and D)

Datum and control points both exist in OPK file, are used in absolute orientation and other aspects of the program. These two types are recognized as object points and have an equal basis in different parts of orientation.

Therefore, especially in bundle adjustment the concepts of the datum point or the datum line are taken into account as following:

- If the bundle adjustment is calculated on compulsory connection (control points /line), the program treats all datum points /line like control points /line.
- If a free network is calculated, all control points /line are used like datum points /line.

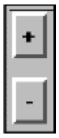
9.4 Editing Orientation Data



The button *orientation data* leads the user for editing (approximate values) of the orientation parameters.

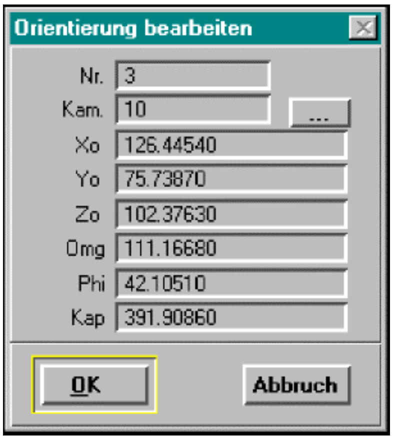
The orientation data are:

Xo, Yo, Zo: Coordinates of the projection center
Omg, Phi, Kap: Rotations of the image coordinate system



9.4.1 Adding and Deleting Orientation Data

The orientation data are rarely edited by the user.



Treatments of orientation data

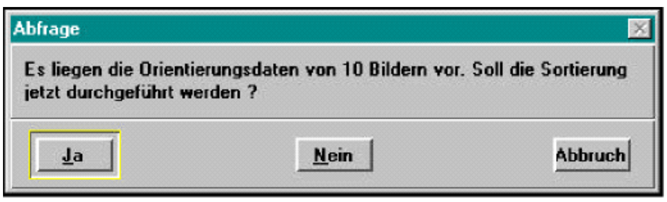
The points can be activated or deactivated by '+' or '–'keys respectively. Inactive points are neglected during bundle adjustment.

In case of having other images which were taken by a different camera the camera numbering this dialog box must be changed to a relevant one.

Indeed, it is to be guaranteed that the camera parameters of the engaged cameras in photography exist in the KAM file before calculation.

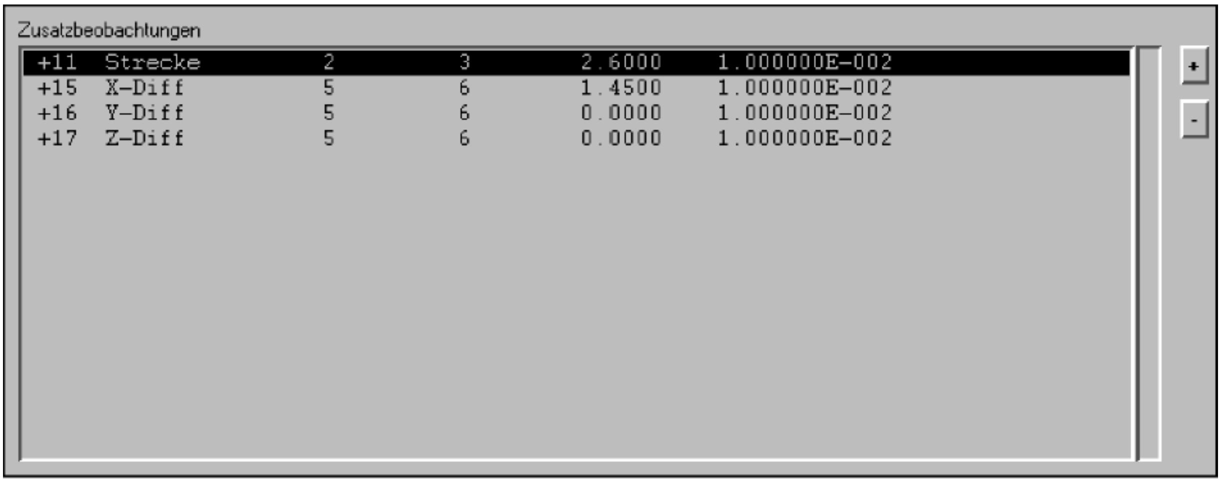
9.4.2 Sorting Orientation Data

by clicking the *"sort"* button and answering the confirmation question with *"Yes"* button the orientation data will be sorted.



Inquiry for assortment of the orientation data

9.5 Editing Additional Observations



In der vorliegenden Version können Zusatzbeobachtungen nur in Verbindung mit Punkten formuliert werden. Für Linien existiert diese Möglichkeit z. Z. noch nicht.

In the present version additional observations can only be formulated for points. For lines this possibility does not yet exist.

The dialog box of additional observations opens by clicking the button "Additional Observation" button.

As additional observations four types of data exist:

1. Coordinates of object points
2. Coordinate differences
3. Camera parameter (interior orientation) 4th orientation parameter of the photographs

The following observation types are possible in detail:

flag	**observation type**	
11	distances (3D)	
12	X value	object point coordinates
13	Y value	
14	Z value	
15	X difference	coordinate differences
16	Y difference	
17	Z difference	
18	Focal length	camera parameters
19	principal point x_h	
20	principal point y_h	
21	radial-symmetric distortion A_1	
22	radial-symmetric distortion A_2	
23	radial-symmetric distortion A_3	

24	tangential-asymmetric distortion B_1	
25	tangential-asymmetric distortion B_2	
26	station X_0	orientation parameters
27	station Y_0	
28	station Z_0	
29	rotation ω	
30	rotation φ	
31	rotation κ	
32	distance between 2 stations	
33	difference in X_0	
34	difference in Y_0	
35	difference in Z_0	
36	difference in ω	
37	difference in φ	
38	difference in κ	

Table of the additional observations

Every additional observation consists of a record which consists of 5 elements:

Type: Type of new additional observation is defined in this filed.

From: as a function of the observation group here stands a point number, camera number or image number.

To: This field is required only for distance observations and coordinate differences and stands for the second point of the line. In other cases it has no use.

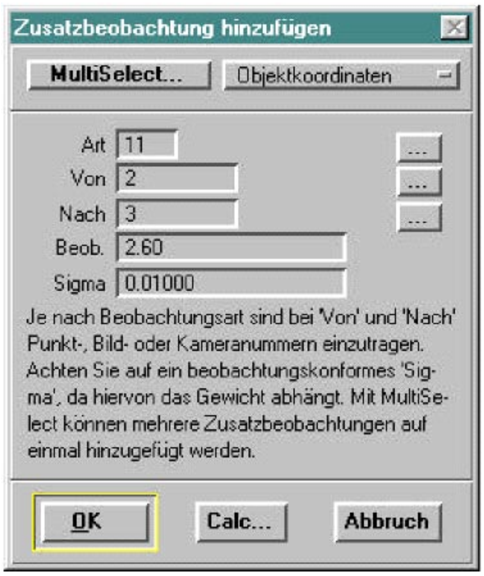
Obs.: Here the observed size is to be put down (e.g., distance measure). The size registered here may show no contradiction to the existing observations. The cause of convergence of bundle adjustment (chapter 10) can lie in faulty additional observations.

Sigma: Standard deviation of the observations determines the weight of additional observation in bundle adjustment (chapter 10).

9.5.1 Adding Additional Observations

At beginning of a new project the list of the additional observations is empty. With the button *“Add” additional observations* are defined. The additional observations can be given either individually, or are grasped equally all at once (Multi-Select).

9.5.1.1 Single Capture



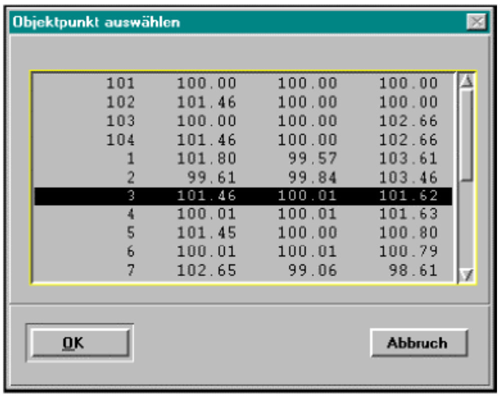
A new additional observation (here: distance of point 2 after 3)

List with the selectable additional observations

To the right of each input field *"Type", "From"* and *"To"* is a switch. Each of these buttons opens a dialog box with all available additional observation types.

The desired type of observation can be selected here in the above dialog box. The lines with an asterisk have a specific feature (----*-). Selection of any of these lines leads to the so-called "Multi-Selection" procedure with which several observation records are generated at the same time (see also chapter 9.5.1.2.).

The button near the text fields *"From"* and *"To"* lead us to observation type - either the list of the object points, the camera data or the orientation data.



Example: Object point selection for formulation of additional observations

Object point list: with distance observations, coordinates and – differences
Camera list: with interior orientation observations to the
Orientation data: with image orientation observations

The standard deviation in the field *"Sigma"* the weight of the respective observation is defined: a small standard deviation causes a very high weight, i.e. the influence of the observation on the result is very strong. Vice versa an observation affects only very weakly if the standard deviation is high accordingly.

It is to be followed that the standard deviations are not entered extremely high or low values because numerical problems can appear in bundle adjustment.

Moreover as an example a distance observation: this observation already gets a high weight if the standard deviation is set to 0.001 m (the object dimensions of architectural photogrammetry are assumed here). In any case, this value should not get lower than 10^{-6}. Distance observation should be weighted weakly.

9.5.1.2 Multiple Capture (MultiSelect)

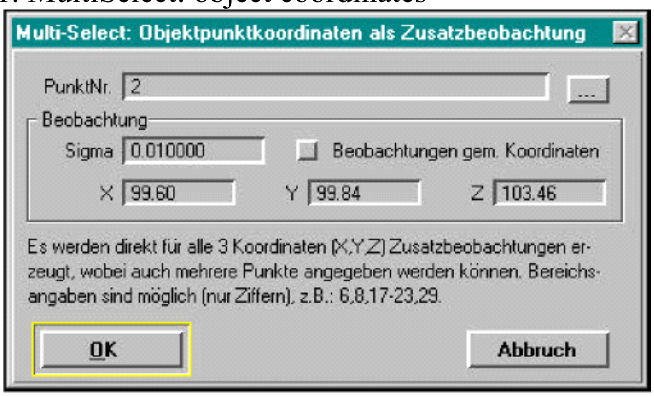
With some additional observations several records are formulated all at once.

If, for example, the coordinate differences between points are set up, this is done mostly for all 3 coordinates X, Y, and Z. Such arrangements can be dealt with rationally by the Multi Select option.

As soon as clicking *the MultiSelect* button another dialog box is opened. Now, besides, the input possibilities depend on the fact which type of observation is selected before clicking the button. The following options are available:

1. Object coordinates
2. Coordinate differences
3. Camera data
4. Orientation data
5. Station differences

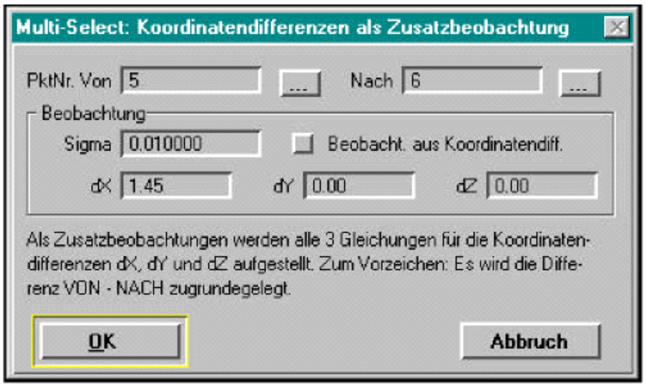
1. MultiSelect: object coordinates

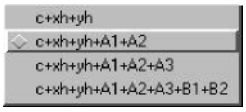


With this dialog box direct observations of the object point coordinates are defined. Then these points are declared not as control points (CP), but as new points (NP). And five filed of additional observations must be considered for these new points.

In the input field *"Point No."* the number dedicated to the point is entered. The area information is possible, by entering the identical coordinates for both the starting and ending point of a polygon.

The observation can be settled either directly in three suitable text fields through the button *Observation of Measured Coordinates* is activated, then coordinate values from the OPK file are used as observation quantities.



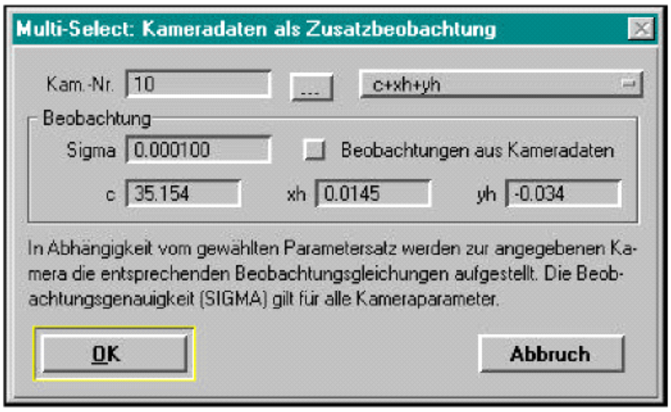


2. MultiSelect: coordinate differences

The definition of coordinate differences as an additional observation can be helpful, for example if one wants to stabilize an image mosaic horizontally or vertically. Then the observations of the coordinate differences for X, Y and Z can be generated between 2 points in each case all at once.

The observations dX, dY and dZ are given either in the relevant input fields. Or one clicks the button *"to observations from coordinate differences";* then at the result the program calculates the difference amounts from the object coordinates and accepts it down as an observation.

3. MultiSelect: camera data



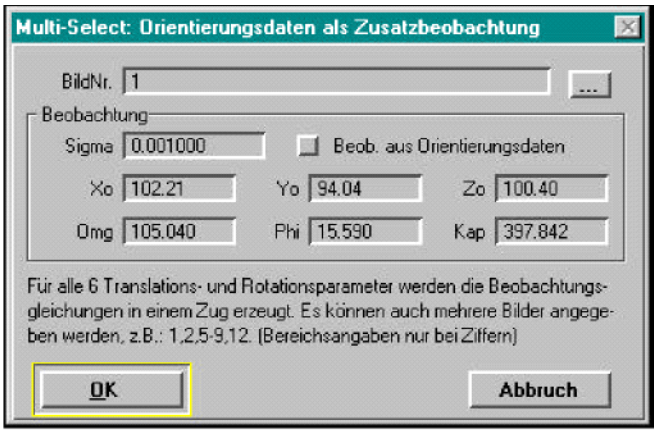
Like object coordinates (see above) the camera parameters are defined as direct observations by which together with the weight appointment the "mobility" of the defaults can be influenced. The single additional observations for the parameters of a camera (interior orientation) can be defined here.

The user can select which camera parameters are taken into account in this dialog filed these sets of camera parameters are at the top on the right of the window. There are the following options:

1. c+xh+yh
2. c+xh+yh+A1+A2
3. c+xh+yh+A1+A2+A3
4. c+xh+yh+A1+A2+A3+B1+B2

Alternatively the button *"observations from camera data"* can be also activated and leads to the fact that the numerical values from the camera file (KAM-file) are used.

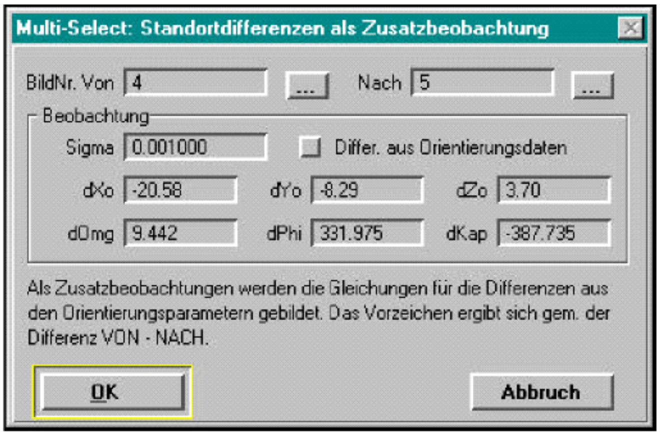
4. MultiSelect: orientation data

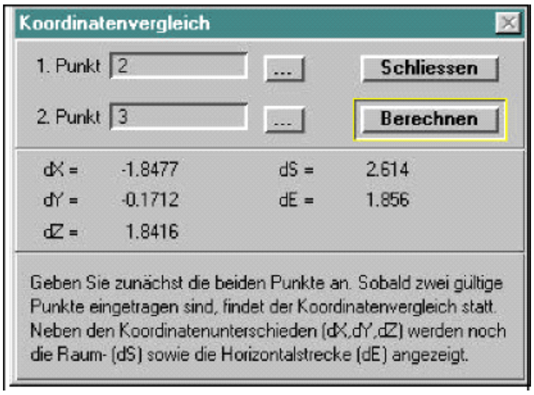


For orientation data, i.e. for the camera location or rotations, one will rarely introduce additional observations in the image orientation because these elements are almost never measured directly. As with the object point coordinates the user can put down several image numbers all at once which are to be distinguished by comma.

The button *observations from orientation data* causes alternatively to the manual input of available values from EOR file as observations.

5. MultiSelect: standpoint differences





In comparison with orientation data the so-called location differences will play a role in the practice rather than as additional observations. It concerns differences in the location coordinates and rotations of two cameras which are formulated as additional observations. On this occasion, the relative positions and rotations of both cameras are determined to each other. It is even often advisable to use this information in the form of the additional observations.

The observation data are also put down in this dialog box like other observation types. The button *"differences from orientation data"* also functions the same. If the button is activated, the program calculates the differences from the data in the EOR file automatically.

9.5.2 Editing Additional Observations

Additional observations can be activated or deactivated by '+' or '-'keys respectively. The respective sign is put next to each observation. They can also be deleted by using the *"Delete"* key.

9.5.3 Coordinate Comparison (Computational Aid)

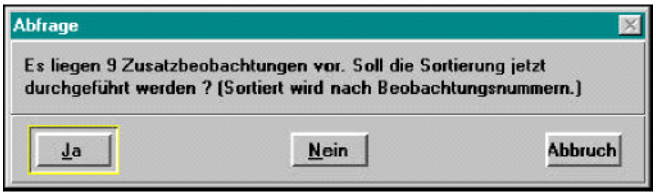
Sometimes it is necessary that the user calculates the additional observations for the difference of coordinate values or the 2D / 3D Distances between points. In these cases the *"Calc"* button is clicked.

In the dialog box *"Coordinate comparison"* are to be given *the 1st and 2nd point*. A list of the available object points is indicated. By selecting points through this list and clicking the button calculate the program calculates the differences and distances between observations.

9.5.4 Sorting Additional Observations

The assortment refers to the flag of the additional observations. Every observation type is recognized as on of the above described from number 11 to 38. Therefore, the assortment occurs on the basis of these observation numbers.

After clicking the button *“Sort”* the program asks the usual confirmation inquiry.



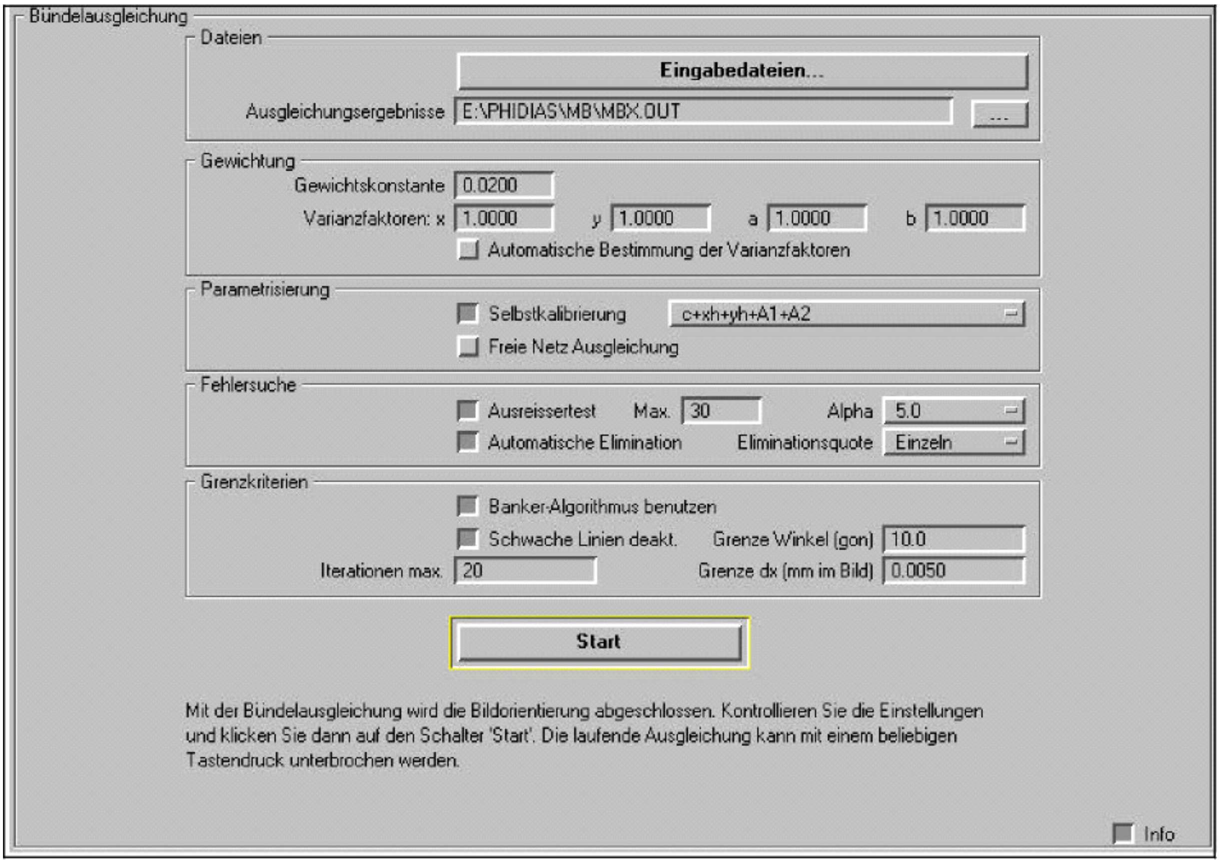
Confirmation inquiry for sorting the additional observations

9.6 Finish Data Edit

By clicking the button *“Finish”* the program asks whether to save the changes. Then by clicking the *“Save”* button the changes will be stored.

Question at finishing *“Edit Data”*

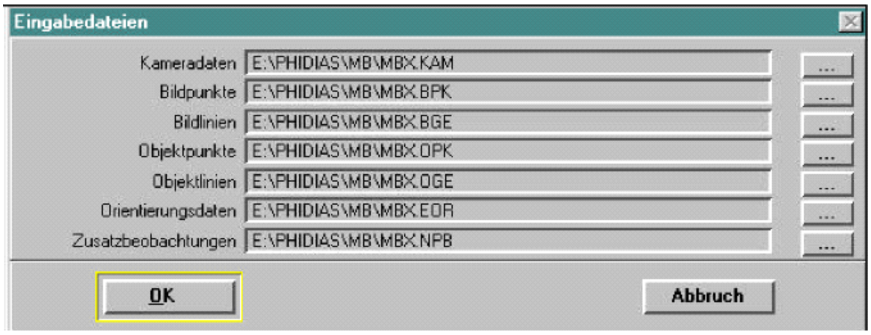
10. Bundle Adjustment



The bundle adjustment as the computationally most expensive part of the image orientation requires the setting of several control parameters.

1. Input Data

If the button *input files* is pressed, a dialog box for all input files appears.



Input files for the bundle adjustment

Generally the suggested files are used. Should they be changed in particular cases, the dialog about has to be left by *OK*. Otherwise *Cancel* does not change the names of the input files.

2. Output File

As default for the file name extension of the result file the program uses .OUT. An existing result file is overwritten in case of a re-adjustment without further inquiry. Thus in this case the user has to save the OUT file on his own.

3. Weight Constant

The weight constant is decisive for the absolute size of the weights. On principle it does not matter which value is entered here.

However, for that no numerical difficulties arise and highest possible arithmetic precision is preserved, the weight constant should be of the size of the (estimated) measurement accuracy (in mm) of the image coordinates. The default 0,020 should generally be maintained.

4. Variance Factors

By use of variance factors the observation weights of the image coordinates x and y as well as the image line parameters a and b can be changed globally. In fact the variances – not the standard deviations – are multiplied by the variance factors and so change directly the weights.

By default the variance factors are set to 1.0 and are generally used so. Other values are conceivable for instance, if there is reasonably assumed that one coordinate was measured with a significantly higher or lower accuracy.

The variance factors can also be determined automatically by so-called estimation of variance components.

5. Automatic Variance Estimation

By activation of this switch the variance factors of x and y image coordinates as well as of line parameters a and b are determined simultaneously during bundle adjustment.

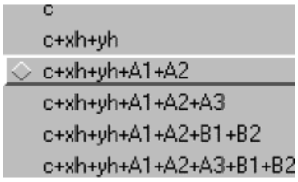
Herewith the actually obtained measurement accuracy – and thus the "true" observation weighting – can be determined objectively by bundle adjustment. The estimation of variance components will generally be done only for special purposes, e.g., to achieve very high accuracy. Therefore it is not active by default, because in general some additional iteration steps are necessary.

The estimation of variance components – if active – should regularly be combined with the free network adjustment, so that the result is free from erroneous constraint points. The result of the estimation of variance factors reported in the result file (chapter 11).

6. Camera Calibration

The calibration parameters of the cameras used can be determined in the course of the bundle adjustment. Therefore the switch *Self-calibration* must be activated.

With the camera calibration several set-ups are possible. The option switch contains the following dropdown menu:



Calibration set-ups

The default set-ups c+xh+yh+A1+A2 works with two parameters A_1 and A_2 for distortion. This set-ups has proven true in most practical applications and should be chosen as a rule.

If the camera calibration is done with even more distortion parameters,this assumes a lot of image observations. The program checks the statistical significance of the distortion parameters and notes this in certain circumstances in the output file (see chapter 11).

If the bundle adjustment does not reach its goal because possibly the procedure does not converge, a trial should be given to the calibration set-ups without distortion (only c or c+xh+yh). Realize that the results of the bundle adjustment – primarily thus the orientations of the images - are not so accurate then.

7. Free Network

If the bundle adjustment is to be calculated as *free network*, the switch must be set.

With the free network adjustment none of the object points / lines is fixed as a control point / line; in this case the image orientation is carried out without strain. The free network adjustment should be activated particularly in conjunction with the estimation of variance components because then the image measurement accuracy is determined without falsifying influence of the compulsory points / lines (control points / lines).

□ The tags of control or datum points (P/D) in the object point file (OPK file) is interpreted depending on the switch for the free network adjustment (cf. chapter 9.3):

- If a free network is calculated, all control points (P) behave like datum points (D), i.e. they contribute like the datum points to the network positioning and are at the same moment stochastic (variable) quantities.
- The other way round all datum points with the adjustment have identical properties as the control points and contribute to the constrained connection of the image mosaic.

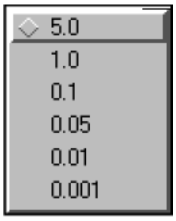
On in case available lines in the adjustment these considerations can be fully transferred.

8. Outlier Test

The program can examine the observations for gross errors. The outlier test should usually be done, i.e. the switch is to be set to *Yes*.

The maximum permissible number of outliers is entered into the input field *Max.*. By default the value 30 is used. If the maximum number is reached during the calculation, this does not signify that the program breaks off the orientation. Then rather only the search for other gross errors ends. Should it turn out that actually more outliers exist, the calculation must be started once more with an increased value of the maximum number.

At *alpha* the confidence level of the outlier test can be set. Usually it is calculated with a value of 5.0%. The dropdown menu contains the following values for the confidence level.



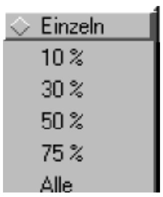
Choice of confidence level

9. Automatic Outlier Elimination

With the automatic outlier elimination possibly appearing errors in the observations are removed automatically, presumed the outlier test is activated (see above).

At this, one can choose how many outliers should be removed after every flow all at once. By default, the elimination type *single* is used. Then after every flow always exactly one observation is taken out of the calculation. After that, the complete bundle adjustment is redone. The cycle recurs, until all blundered observations are removed.

The elimination type *single* should be ordinarily used always because this is in accordance with the theory of outlier search. According to this, namely the existence of only one outlier in each case is assumed. Then, however, with projects with a very high number of observations the calculation lasts possibly very long. In these cases the number of outliers to be removed per flow can be increased if necessary. The following elimination types can be set:



List of the available elimination rates for the automatic outlier elimination

If, for example, *30%* is chosen as elimination rate, in every flow immediately 3/10 of the outliers are removed, that is the biggest ones in each case.

□ This is done in such a way that to every object point always only one observation is eliminated. Often the case appears that a point is indicated as blundered in several images at once, due to blurring effects of the least

squares estimation. The larger
the error is in an observation, the stronger this phenomenon is given. In these cases such a point is removed only in one image, that is where the largest error is indicated.

Provided that in the bundle adjustment points and lines are used at the same moment, the system described here applies to both data types in parallel. If, for instance, the outlier elimination is set to *single* and in a flow gross errors are detected at both observation types, the faulty point as well as the blundered line is eliminated.

10. Banker's Algorithm

The adjustment program has an implementation of the so-called banker's algorithm. By this, the unknowns are resorted such that the equation system is to be solved most economically and thus fast. Especially at larger projects this option becomes apparent in a clearly quickened computational process.

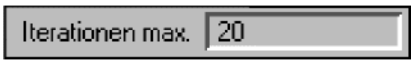
In some cases – especially if the adjustment is done as a free network – the banker's assortment may produce instead of, as desired, reduced equation systems, also slightly larger ones. If this is the case, an appropriate message is displayed. In these cases the algorithm can be also deactivated, because the assortment yields no time advantage.

11. Deactivate Weak Lines

This option has only a meaning, if the image orientation is done with the aid of lines. Weak lines are such lines which are determined under a very sharp angle, like a glancing intersection of arcs. Such lines are mostly very uncertain. In addition, they can disturb the whole adjustment process, so that the automatic deactivation should be switched on by default. In the result output it is informed about perhaps appeared weak lines.

The program checks automatically during the calculation whether weak lines exist. As a test criterion is taken the maximum cutting angle formed by the spatial straight lines. The lower limit is 10 gon by default, but can be adapted individually to the situation. In particular cases this has to be done empirically.

12. Iterations



Adjustment tasks are generally an iterative process. The user can set the maximum number of the iterations, which is 20 by default.

If the maximum is reached, the bundle adjustment is not automatically stopped. In this case there appears a dialog in which the number of iterations can yet be increased at first.

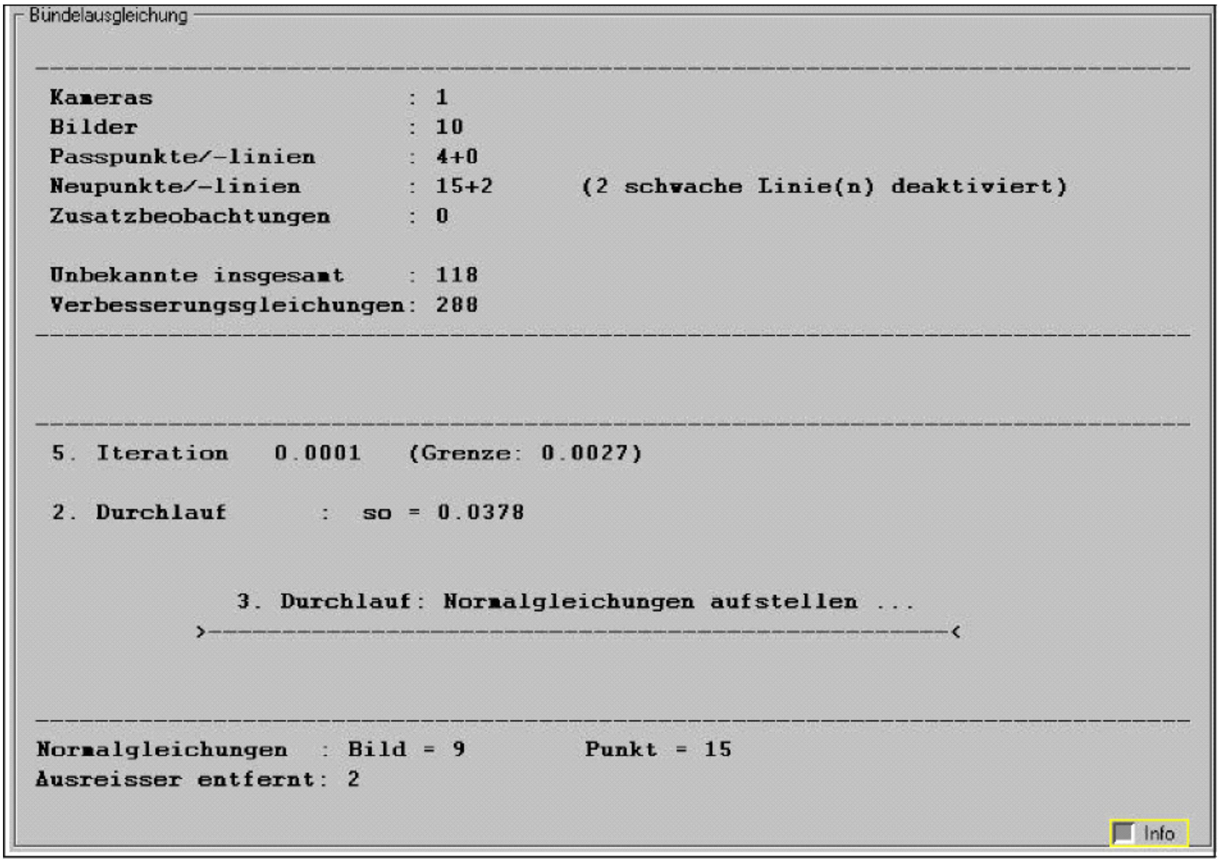
13. Limit Value dx

The limit value **dx** is the stop criterion of the bundle adjustment: When the largest increment to an unknown from the adjustment is smaller than the value dx related to image scale – the increment is thus converted into the image system –, the convergence goal is reached.

> The default for dx is 5 µm and convergence is regarded as achieved in this case, if the largest value among the increments of the unknowns is less than 5 µm in the image. As a realistic value for dx half of the estimated image measurement accuracy is to be taken in general.

The actual bundle adjustment begins with *Start*.

10.1 Screen Output During Calculation



Screen output during the bundle adjustment in the example MBX. In this case it is calculated with constrained connection and with automatic flow.

10.1.1 Data Statistics

In the upper part of the screen some information is given to the extent of data of the projects which are self-explicatory mainly. The object data are distinguished as to points and lines. Thus in the screen shot there are stated 15 new points and 2 new lines (15+2).

The number of the new lines may well be smaller than those of the actual existing ones in the OGE file. There are in principle two causes for this:

1. On the one hand, so-called weak lines can be deactivated (also compare the statements above about the switch of the same name). In this example this applies evidently to two lines.

2. Moreover, all new lines which are measured in only two images are from the outset taken out of the adjustment . With only 2 measurements there is no redundancy and an adjustment makes no sense. Therefore, all lines to which this applies, are calculated not till later at the output of results (see below).

10.1.2 Statements During an Iteration

In the line

```
1. Iteration   2.1383   (Grenze: 0.0030)
```

the momentary state of the iterative calculation is stated. In this example the first iteration has been done and the sum of squared increments of the unknowns is 2.1383. The convergence goal is reached, if the limit (here 0.0030), which depends on the value dx (see above), is fallen below.

An iteration consists of

- the establishment of the normal equations and
- the factorization,
- as well as – after achievement of the convergence goal – the inversion.

In the activity line

```
3. Durchlauf: Normalgleichungen aufstellen ...
```

the current activity within an iteration step is indicated.

10.1.3 Statements After Each Flow

At the lower edge of the display area

```
Ausreisser entfernt: 2
```

it is reported after each flow about the number of eliminated outliers. So long as gross errors still exist, the adjustment cycle recurs.

Also the standard deviation of unit weight (s_0) is calculated after every flow and is currently indicated.

```
1. Durchlauf      :  so = 0.0820
```

10.1.4 Standard Deviation of Unit Weight σ_0

This value should in the end of the bundle adjustment in the ideal case be equal to the given weight constant (mostly 0,020). If this is not the case, there are in practice principally two causes:

1. At beginning of the calculation cycle generally still some outliers exist. Then the value for σ_0 is also still much larger. The more gross errors are eliminated, the smaller becomes σ_0.

2. If the result differs for σ_0 still clearly from the given weight constant, although no more gross errors are indicated, the cause is to be seen in the fact that the standard deviations of the image observations a priori, thus the numerical values in the BPK file and the BGE file do not correspond to reality. They are, absolutely seen, set either too high or too low; or the accuracy ratio of the observations to each other is not correct .

It is not indispensable to bring the standard deviation s_0 from the adjustment into coincidence with given weight constant. Since the result of the image orientation does not depend on the absolute amount of the standard deviations of the image observations. Whether e.g. the accuracy for x and y coordinates is set to 20 µm or 40 µm each, has no influence on the orientation result.

Important is rather the ratio of the accuracies of both observation groups. The bundle adjustment yields other results if, for instance, the x coordinates are introduced with 20 µm and the y coordinates with 30 µm.

Should even though, for certain reasons, the value for s_0 be brought into coincidence with the weight constant, the following actions can be taken alternatively:

- The automatic determination of the variance factors is switched on. At this, the program determines automatically the correct ratio of the accuracies. At the end of the calculation the value for s_0 must be (nearly) identical with the weight constant.

- The variance factors are set by hand in the input mask of the bundle adjustment. Which factors are to be entered, can be gathered from the result file (chapter 11). There the suggestions for the variance factors are made. The variance factors must be adapted in several flows, until the identity is reached.

- The most expensive action is the adaptation of the observation accuracies (σ_x and σ_y resp. σ_a and σ_b). For this the suitable suggestions are made in the result file, too. This way is so expensive, because the changes must done to all points in all images uniformly.

  This action must also be repeated several times, like the adaptation of the variance factors.

 Provided that image points and image lines are used together in the adjustment, the application of the estimation of variance components is recommended regularly. Since the a priori variances of the image line parameters (a and b) are just hard to estimate, that is their relation among each other as well as the relation to the image point coordinates. For higher accuracy claims the estimation of variance components can do a good job.

10.1.5 Screen Output on Automatic Variance Estimation

If the automatic variance estimation is active, in addition to s_0 the current values of the variance factors are displayed after each flow, e.g.:

```
Varianzfaktoren    : x/y = 2.5654 1.3176     a/b = 0.0602 0.3408
```

Because estimation of variance components is an iterative process, these values change with every flow, until the final result is reached.

10.1.6 Too Few Control Points / Lines in Automatic Calculation

If the complete image orientation runs automatically from the beginning (chapter 6) and in the bundle adjustment is found out that there are too few control points and control lines to define the image mosaic, then the program switches over automatically and without further inquiries to the free network adjustment. At the same moment all new points / lines (N) and control points / lines (P) are declared as datum points / lines (D) and the bundle adjustment processes the whole image mosaic as a free network.

In this case appears on the screen - as well as in the protocol file (log file) to the automatic orientation occurrences - a suitable tip:

Notice: Too few control points! All CP and NP were set to DP.

The automatic switching to free network adjustment does not occur if the bundle adjustment is done under the control of the user.

10.2 Bundle Adjustment Without Automatic Flow

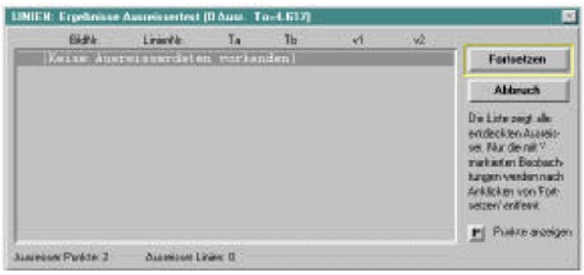
The term "automatic flow" signifies that all blundered observations are removed automatically by the program. This is done in steps, i.e. per flow only one (in case also more, see above) observation is eliminated and afterwards the bundle adjustment is recalculated.

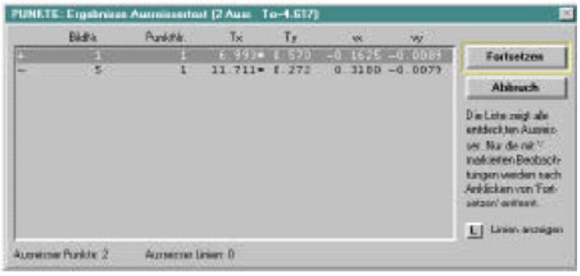
10.2.1 Call Outlier Test

If the switch for the automatic outlier elimination is on ‘No’, the list with the found errors is displayed after the the outlier test. If no outliers are found, the program goes over immediately to the result output.

10.2.2 Display Outliers

If one or several gross errors are discovered in the observations, a window with the list of the blundered image data appears:





Display of the discovered outliers (here 2 in the image points and 0 in the image lines); depending on the elimination rate the largest are marked with a minus sign. The display can be toggled between image points and image lines using the switch *Display Points / Display Lines*.

Alongside the image number, point number and line number for identification, there are stated in this list in each case:

Tx, Ty: test statistics of the outlier test for x resp. y coordinate. The current limit value *To,* above which a coordinate observation is declared as faulty, stands in the title line.

In this example the limit is at 4.617 and to outliers were discovered among the image points.

 If as test statistics the value 9.999 or 0.000 is put out, there is mostly a singularity in the image orientation; this is, e.g., the case if too little (independent) control information for the fixation of the image mosaic has been introduced.

vx, vy: under these names the corrections are given in the unit of the image coordinates (as a rule, mm).

Ta, Tb: Analogously to the image coordinates there are respective test statistics for the image line parameters a and b. To them applies the same as to Tx and Ty.

v1, v2: the corrections va and vb for the image line parameters are not stated here because these are not directly interpretable and, therefore, of little evidence. Instead, the auxiliary corrections v1 and v2 are stated, which arise as follows: the end-points of the adjusted space lines are transformed to the image, using the current orientation parameters. The shortest distances of the thus created image points from the corresponding image line are the quantities v1 and v2. This signifies that the auxiliary corrections are counted like vx and vy in mm.

10.2.3 Eliminate Outliers

By default, the program marks the largest of several outliers in the list with a minus sign, where size is assessed using the test statistics, thus not the corrections. Through this the relevant observation is inactivated and does not take part anymore in the next flow of bundle adjustment. If another elimination rate than *Single* has been set (see above), acoordingly more observations are marked with minus signs.

The user can inactivate further observations with the minus key; though this is generally not recommended, because due to so-called blurring effects which are caused by the statistical adjustment calculations, some image observations can be declared as faulty, although they are not at all. That is why always only one observation should be eliminated per flow.

Only if there are very many outliers it can make sense to inactivate several observations at once, in order to speed up the calculation process.

With the plus key, records can be set active again. However, once eliminated image observations are lost for the current adjustment process; otherwise the bundle adjustment would have to be restarted from the beginning.

10.2.4 Continue Program After Outlier Test

The button *OK* closes the list of outliers again and the bundle adjustment starts from the beginning, but now without the deactivated image observations. Cyclic eliminating of outliers is repeated until the program finds out none more.

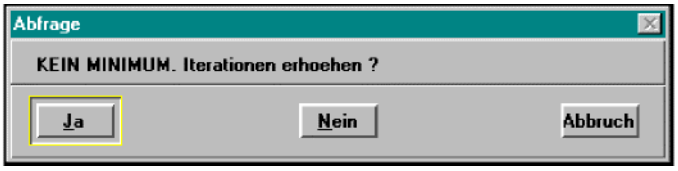
Is *Cancel* pressed instead, the program ends the adjustment process and goes over immediately to the results output. On the results output the outlier test is executed once more and all faulty observations still present then get a suitable marking.

10.3 Interruption of Bundle Adjustment

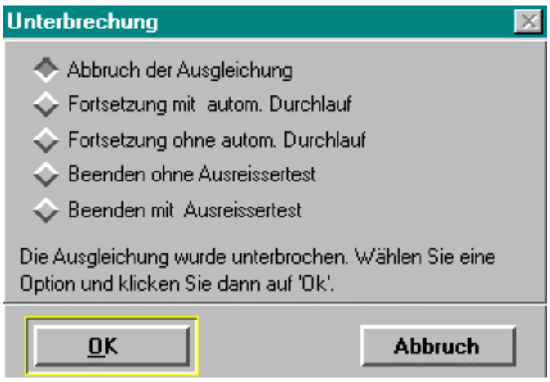
Interruption of the – sometimes longer lasting – bundle adjustment can be caused by the program as well as by the user.

10.3.1 Interruption by Program

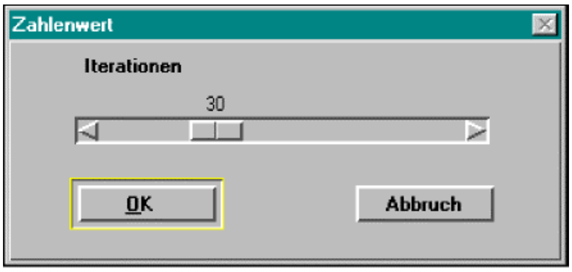
A program-sided interruption is, for example if the given maximum number of iterations is reached:



Dialog at reaching the maximum number of iterations



In this case the calculations are interrupted and it appears a relevant Yes / No dialog. The number of iterations can be increased by *Yes* and then the bundle adjustment continues.



Dialog box to increase number of iterations

10.3.2 Interruption by User

If any key is pressed during the calculation, the program stops and a selection box appears:

Interruption after pressing any key

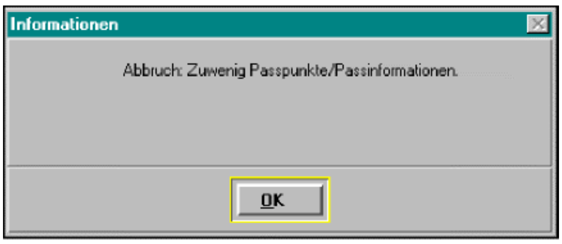
Now one of five options can be chosen:

1. **Abort** of the adjustment. No result output takes place.
2. The bundle adjustment can be continued **with** automatic flow.
3. The bundle adjustment can be continued **without** automatic flow.
4. The bundle adjustment can be finished **without** final investigation for outliers.
5. At last, the bundle adjustment can be finished **with** a final investigation for outliers. The thereby indicated outliers are in general of little eveidence, because the procedure perhaps has not reached the convergence goal yet.

Pressing *Cancel* closes the selection box again and the program starts to calculate again, where it has been interrupted.

10.4 Error Messages

After the start of the bundle adjustment a huge number of causes can lead to a premature end of the calculation. In these cases a short notice about the reason for the termination appears.



Example of an error message

The program is continued then by clicking *OK.*

10.5 End of Bundle Adjustment

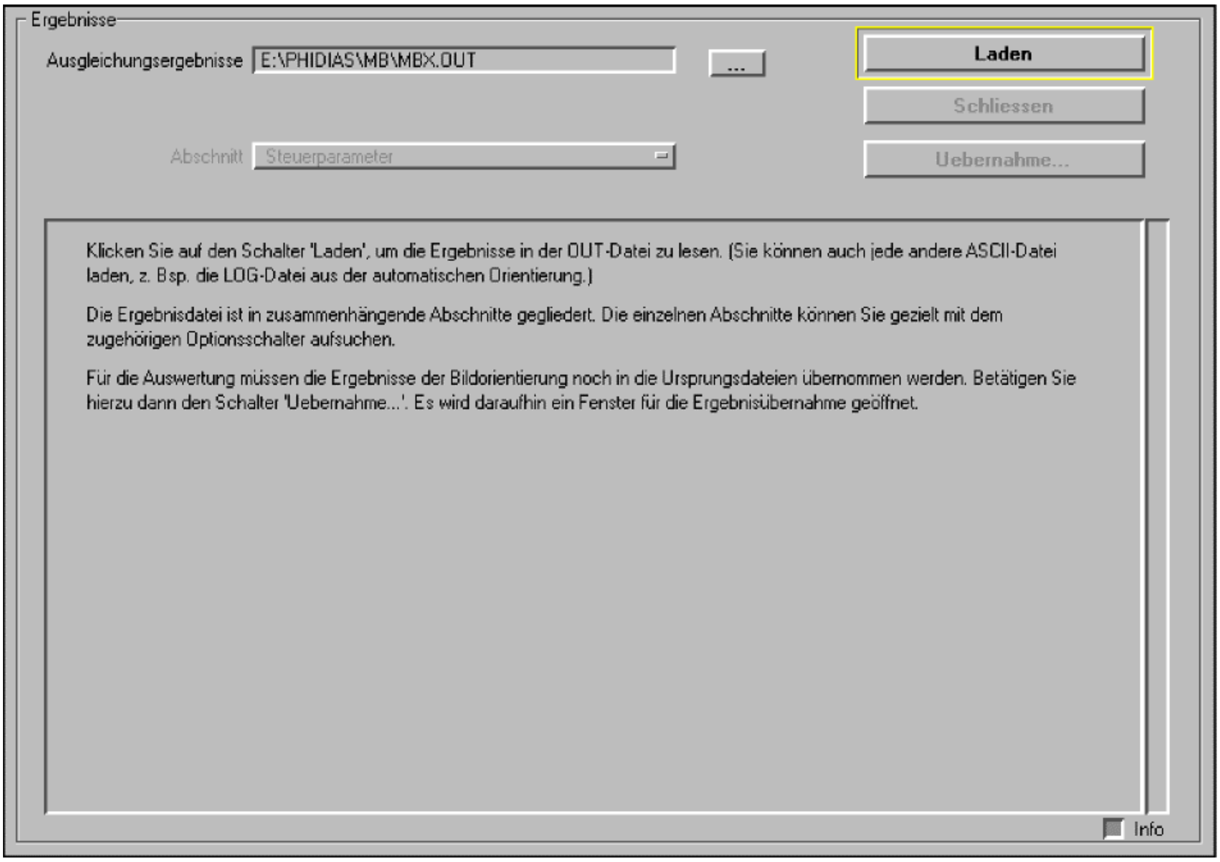
If the bundle adjustment could be executed successfully, a message informs about the end of the calculations:

Screen display at the end of the bundle adjustment (in part)

On the output of the results an outlier test is executed once more. In the bottom line of the display area stands then the number of the gross errors discovered last as well as discovered altogether.

Finally, the program expects the *OK* button to be clicked.

11. Results



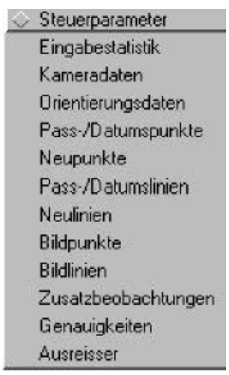
The results of the bundle adjustment are summarized in one file:

MBX.OUT: name of the result file. The default of the file name extension is .OUT.

The data of the result file are loaded with the button *Load* and there appear the first lines on the screen. As soon as this has happened, the display can be shut again by *Close*.

11.1 Go Straight to a Section

The whole result file is arranged in a total of 13 main sections. These sections can be looked up straight with the option switch *section.*



Sections of the result file

With this the section currently selected in the list can be directly accessed. The cursor is then at the beginning of the respective section.

11.2 Explanation of the Result Data from Bundle Adjustment

The results from the bundle adjustment are made up on the output of a total of 13 sections (see also chapter 11.1.1). The contents of these sections are explained in the following chapters.

Generally applies that only those data appear in the output file which have been also used in the bundle adjustment. Consequently a control point for which exist no image measurements at all is not used and is therefore also not listed in the result file.

11.2.1 Control Parameters

```
--------------------------------------------------------------------
---Control Parameters -----------------------------------------------
--------------------------------------------------------------------
Camera data from                : E:\PHIDIAS\MB\MBX.KAM
Image points from               : E:\PHIDIAS\MB\MBX.BPK
Image lines from                : E:\PHIDIAS\MB\MBX.BGE
Object points from              : E:\PHIDIAS\MB\MBX.OPK
Object lines from               : E:\PHIDIAS\MB\MBX.OGE
Orientation data from           : E:\PHIDIAS\MB\MBX.EOR
Additional observations from    : E:\PHIDIAS\MB\MBX.NPB
Name of the result file         : E:\PHIDIAS\MB\MBX.OUT
Iterations at most              : 20
Iterations altogether           : 4
Weight constant                 : 0,020
Variance factors x and y        : 1.0000     1.0000
a and b                         : 1.0000     1.0000
Interior orientation            : Yes
Parameter sentence              : c+xh+yh+A1+A2
Free network                    : No
Outlier test                    : Yes
Alpha                           : 5,000
Fractile                        : 4.608
Autom. Variance estimation      : No
Atomatic flow                   : No
Limit dx (mm in the image)      : 0.005000 (= 0.0027 m in the object)
Weak lines deactivated          : Yes
Limit angle                     : 10.0
Banker’s algorithm              : Yes
```

The section of the control parameters documents in the central issue all defaults made by the user at the beginning of the bundle adjustment (see chapter 10). The entries reflect the definitions in the input mask there and are self-explicatory in this respect.

In addition, the fractile is given, that is the limit value for the assessment of an outlier in the observations. The outlier test is executed at a pre-selectable confidence level. In the result file stands in each case the fractile of the last flow of the bundle adjustment (here 4.608).

11.2.2 Input Statistics

```
--------------------------------------------------------------------
---Input Statistics   ----------------------------------------------
--------------------------------------------------------------------
Number of the images        :         10
1. Image   2 with 11 points /    2 lines
```

2. Image	1 with 13 points /	0 lines			
3. Image	3 with 13 points /	0 lines			
4. Image	4 with 13 points /	0 lines			
5. Image	6 with 14 points /	0 lines			
6. Image	7 with 14 points /	0 lines			
7. Image	9 with 14 points /	0 lines			
8. Image	5 with 15 points /	2 lines			
9. Image	10 with 15 points /	2 lines			
10. Image	8 with 16 points /	0 lines			
Number	Control points	:	4		
Number	New points	:	15		
Number	Control lines	:	0		
Number	New lines	:	2	(2 weak lines (n) deactivated)	
Number	To unknowns:	118			
Number	image observations .:		288		
Number	additional observations		:	0	
Profile elements before	:	5268			
Profile elements after	:	3979			

The input statistics give information about the number of the single data elements and need so far no other explanation. The information profile elements before / after gives an impression of it, how big the advantage is by the banker's algorithm. Under the term of profile elements all elements of the normal equation matrix are understood which are really occupied. Their number after the assortment should be smaller regularly.

The images are sorted not according to numbers, but they state the actual order at the bundle adjustment. On this occasion, since the photos are ordered in view of the saving by computational storage optimally. (Provided that is calculated with banker's assortment, however, this order is only temporary).

11.2.3 Camera Data

```
--------------------------------------------------------
---Camera Data------------------------------------------
--------------------------------------------------------

camera no.          :       10        ro: 20.00
---------------------------------
c                   :    37.2734   +/-     0.2803   d:      2.2734 mm
xh                  :     0.0245   +/-     0.1938   d:      0.0245 mm
yh                  :    -0.0814   +/-     0.1936   d:     -0.0814 mm
a1       (1.e-4    ):    -0.2078   +/-     0.1609   d:     -0.2078   Not significant!
a2       (1.e-7    ):     0.4064   +/-     0.3509   d:      0.4064   Not significant!

         ¦         c         xh        yh A1     A2
         +
c ¦      1.00      0.41      0.19      -0.09     0.31
xh ¦               1.00      -0.14     -0.23     0.36
yh ¦                         1.00      0.41      -0.29
A1 ¦                                   1.00      -0.92
A2 ¦                                             1.00
```

In the section *Camera data* stand the calibration results of the cameras. Three informations are made for each parameter what should be explained using the example of the **camera constant c**.

c : 37.2734 +/- 0.2803 d: 2.2734 mm

37.2734	: the adjustment result of the respective size (here camera constant)
0.2803	: the standard deviation (in the unit of the accompanying parameter)
2.2734	: the whole surcharge with the adjustment opposite the approximate value

If is calculated with the bundle adjustment without self-calibration (i.e. the switch *for self-calibration* stands on NO, see chapter 10), the standard deviation and the surcharge value are put to zero.

Further is informed in the section *Camera data* in a table

	c	xh	yh	A1	A2
c	1.00	0.41	0.19	-0.09	0.31
xh		1.00	-0.14	-0.23	0.36
yh			1.00	0.41	-0.29
A1				1.00	-0.92
A2					1.00

about the correlation coefficients between camera parameters. Values near with +1 or-1 point to a strong dependence. Thus a high correlation exists, for instance, always between the distortion parameters A1 and A2 which is founded in the mathematical arrangement.

11.2.3.1 Distortion Parameters

The distortion parameters are checked, in addition, for significance, i.e. it is examined whether these values within the current project with statistical significance can be determined. If this is not the case, a suitable notice appears:

Not significant!

11.2.4 Orientation Data

The external orientation parameters, thus the orientation data of the photos, are given in two representation forms:

1. in the overview and 2. in detail

11.2.4.1 Orientation Data in Overview

--In Overview---

Image	Cam	Xo	Yo	Zo	Omg	Phi	Kap
-----	---	-------	-------	-------	--------	--------	--------
1	10	102.401	93.661	100.426	104.3523	16.4671	397.8555
2	10	99.010	92.866	100.304	104.5083	384.7244	400.4475
3	10	128.166	74.699	102.533	110.2314	43.5024	392.8985
4	10	81.994	83.607	104.556	110.3100	350.9377	7.4873
5	10	103.377	92.091	100.409	102.9717	20.5393	398.0555
6	10	112.531	71.540	102.384	109.7661	14.4009	396.4139
7	10	112.912	71.487	102.317	109.5623	14.2257	398.2193
8	10	99.566	72.057	102.215	110.4954	388.8818	397.2177
9	10	97.908	94.155	100.385	107.9047	371.3042	1.8874
10	10	95.870	94.548	100.357	107.0352	355.8622	3.2365

With the representation in the overview six elements of the orientation parameters are put together as table. This facilitates the comparison of the results.

11.2.4.2 Orientation Data in Detail

--In Detail---

Image No.: 1 10

X0:	102.4006	+/-	0.031	d:	0.346 m
Y0:	93.6615	+/-	0.037	d:	-0.314 m
Z0:	100.4260	+/-	0.023	d:	-0.033 m
Omg:	104.3523	+/-	0.354	d:	-0.022 gon
Phi:	16.4671	+/-	0.339	d:	2.547 gon
Kap:	397.8555	+/-	0.098	d:	-0.091 gon

Image No.: 2 10

X0:	99.0104	+/-	0.031	d:	-0.071 m
Y0:	92.8662	+/-	0.049	d:	-0.477 m
Z0:	100.3045	+/-	0.021	d:	0.024 m
Omg:	104.5083	+/-	0.346	d:	-0.675 gon
Phi:	384.7244	+/-	0,360	d:	0.321 gon
Kap:	400.4475	+/-	0.099	d:	0.105 gon

Here, the following information (exemplarily explained for X_0 of the photo No. 1) is made for the individual parameters of the external orientation:

102.4006: the adjusted X coordinate of the location
0.031 : the accompanying standard deviation
0.346 : the surcharge with the adjustment opposite the approximate value

High increases (e.g., *d* is for rotation angles greater than 10 to 20 gon) point, as a rule, to unsteady exposure configurations. Otherwise the divergences are opposite the approximate values of less of importance.

11.2.5 Control Points / Datum Points

In dependence on whether the bundle adjustment was calculated free network or not datum or control points are given.

11.2.5.1 Control Points

---Control Points------------------------------------

Point no.	X	Y	Z
101	100.0000	100.0000	100.0000
102	101.4600	100.0000	100.0000
103	100.0000	100.0000	102.6550
104	101.4600	100.0000	102.6550

In the section *Control Points* all fixed points are listed in tabular form. Other informations - as for example statistical characteristics – does not apply to control points.

11.2.5.2 Datum Points

With the free network adjustment it is worked with datum points which dispose of the storage of the image mosaic.

The datum points are given in the identical manner like the new points, so that is expelled at this point to descriptions there. The section has only one other heading:

---Datum Points---

11.2.6 New Points

The new points are shown like the orientation parameters in the overview as well as in detail.

11.2.6.1 New Points in Overview

- in Overview

Point No.	X	Y	Z	s
--------	---------	---------	----------	----
	101.9576	99.7209	103.6764	8
2	99.5955	99.8397	103.4779	10
5	101.4596	100.0060	100.7939	10
6	100.0008	100.0043	100.7842	10
7	102.7217	99.0857	98.5923	3
8	100.4675	99.9829	100.1082	6
9	101.6576	100.0824	103.9955	9
10	100.6193	100.0196	99.5757	10
11	100.5671	100.2324	101.4917	7
12	97.2217	99.9070	114.9574	5
13	96.7916	99.4264	116.3560	5
14	110.4149	100.2763	113.6180	3

The tabular arrangement of the new point coordinates facilitates the comparison of points. In the last column stands the number of image rays with which the suitable point is determined.

11.2.6.2 New Points in Detail

-- In Detail---

Point No.	:	1				

X	:	101.9558	+/-	0.004	d:	0.159 m
Y	:	99.7221	+/-	0.006	d:	0.149 m
Z	:	103.6731	+/-	0.004	d:	0.062 m

Point No.	:	2				

X	:	99.5971	+/-	0.003	d:	-0.016 m
Y	:	99.8407	+/-	0.005	d:	0.002 m
Z	:	103.4757	+/-	0.004	d:	0.012 m

Point No.	:	3				

X	:	101.4657	+/-	0.002	d:	0.005 m
Y	:	100.0121	+/-	0.004	d:	0.002 m
Z	:	101.6176	+/-	0.002	d:	-0.005 m

The information to every coordinate can be explained using the X value by point No. 1:

101.9558 : the adjusted X coordinate
0.004 : the accompanying standard deviation
0.159 : the surcharge with the adjustment opposite the approximate value

The standard deviation is given in the same dimension like the coordinate. The surcharge amount gives an impression of it how well the approximate values of the object point could be determined.

The number of a new point with an exclamation point (!) can be marked on the output as a special case:

Point No. : 4! (less than 2 image observations because of outliers)----------------------------------

This case appears when during the adjustment so much observations than outlier are removed that less than 2 are left and therefore a determination of the point is no more possible. Then this point is disused during the adjustment to a certain extent. By the result takeover (see chapter 11.3) no transference occurs, in addition, into the OPK file.

11.2.7 Control Lines / Datum Lines

Provided that is worked in the orientation with straight lines, the suitable output occurs for control and datum lines or new lines.

11.2.7.1 Control Lines

```
------------------------------------------------------------------
---Control Lines------------------------------------------
--------------------------------------------------------

X1      Y1      Z1      X2      Y2      Z2
--------------------------------------------------------
LIN01 99.855 100.195 103.034 99.849 100.231 102.227
LIN07    101.569 100.259 100.536 101.635 100,300    99.575

Line no. S        Alpha    Beta     Gamma   Delta    s
-------------------------------------------------------------
LIN01 3 0.007435-0.044610 99.0889 104.7913 3
LIN07 3 -0.068678         -0.042664         108.4737104.54832
```

The object lines are shown always in two ways. On the one hand, represented by both three-dimensional end-points. In every line stand the X, Y, Z coordinates of these points which can be geometrically interpreted well. Moreover, the line parameters of the 2-view projection are given in addition as they are used internally by the program (see also chapter 14). The meaning of the single numerical values is:

LIN01	: line number or ID
3	: representation system
0.007435	: parameter α (gradient)
-0.044610	: parameter β (gradient)
99.0889	: parameter γ (axis intercept)
104.7913	: parameter δ (axis intercept)
3	: number of the image rays

11.2.7.2 Datum Lines

To *datum lines* applies the same as to the datum points: the output occurs in similar way like that of the new lines, so that can be referred to there.

11.2.8 New Lines

The *new lines* are described in the overview as well as in detail.

11.2.8.1 New Lines in Overview

---New Lines---

---In Overview--

Line No.	X1	Y1	Z1	X2	Y2	Z2	s
LIN05	100.032	100.296	100.401	100.004	100.336	99.562	3
LIN03	101.629	100.135	103.818	101.641	100.161	103.135	2 *
LIN10	100.323	100.249	101,820	101.498	100.188	101.814	2 * !
LIN09	(Deactivated, because Wmax only 8.1 gon)						
LIN11	(Deactivated, because Wmax only 2.9 gon)						

Line No.	S	Alpha	Beta	Gamma	Delta	s	
LIN05	3	0.033516	-0.047079	96.6667	105.0232	3	
LIN03	3	-0.017209	-0.037219	103.4160	103.9993	2	*
LIN10	1	-0.052101	-0.005478	105.4757	102.3697	2	* !
LIN09	(Deactivated, because Wmax only 8.1 gon)						
LIN11	(Deactivated, because Wmax only 2.9 gon)						

'*' = Lines were determined extra, because only in 2 images available.
! ' = determination is uncertain, because cutting angle below 10 gon.

The new lines are shown with their end-points as well as their internal parameters. The explanation of the latter has already occurred in the section control lines, it should not be repeated here.

Beyond it, further information can appear at this point in the output file:

- LIN09 (Deactivated, because Wmax only 8.1 gon)

  If the option was switched on to the deactivation by so-called weak lines and single lines fall under this criterion, this is documented with a suitable note. In this example it was attached as a minimum angle 10 gon which was remained with 8.1 gon, however.

- LIN10 1-0.052101-0.005478 105.4757 102.3697 2 *!

  In the end, marks can appear at the end of the line. Then an asterisk (*) signifies that this line is measured from the outset in only in two images. Because in this case there is no redundancy, the inclusion in the adjustment yields no advantage. Therefore, the line was determined only after the adjustment by a single intersection. If then turns out that the angle between the planes ("image rays") determining the lines is below the current minimum angle (by default 10 gon), an exclamation point (!) is set in addition.

11.2.8.2 New Lines in Detail

--In Detail---

Line no.: LIN01

P.	: 3		Wmax: 33.1 gon	
Alp:	0.011502	+/-	0,010 d:	0.004 m
Bet:	-0.037944	+/-	0.023 d:	0.007 m
Gam:	98.6588	+/-	0.014 d:	-0.017 m
Del:	104.0908	+/-	0,030 d:	-0.023 m

LineNo.: LIN05

P.	: 3		Wmax:	33.4 gon	
Alp:	0.033626	+/-	0,010	d:	-0.002 m
Bet:	-0.046980	+/-	0.023	d:	-0.000 m
Gam:	96.6553	+/-	0.014	d:	-0.008 m

Del:	105.0128	+/-	0,030	d:	-0.013 m

The information to every line occurs like with the new points, only that now the 3D line parameters α, β, γ and δ instead of X, Y, Z are given. In addition, as Wmax the maximum angle is given under which the image rays (planes) intersect, which determine the lines. The closer this value is to 100 gon, the better this is for the determination certainty.

11.2.9 Image Points

```
-------------------------------------------------------
---Image Points-------------------------------------------
-------------------------------------------------------
```

Image	Point	x	y	vx	vy	Tx	Ty
-----	------	-------	-------	-------	-------	-------	----------
1	1	6.5268	17.1973	0.0211	-0.0226	3.26	2.92
1	2	-6.2981	13.9023	0.0039	-0.0079	0.41	0.85
1	3	4.1471	4.4323	0.0040	0.0220	0.35	1.74
1	4	-3.8299	4.0163	-0.0089	0.0178	0.79	1.32
1	5	4.2261	-0.3255	0.0071	0.0149	0.63	1.15
1	6	-3.8046	-0.6275	-0.0079	0.0084	0.72	0.63
1	8	-1.3174	-4.3856	-0.0010	-0.0074	0.09	0.55
1	10	-0.3816	-7.4270	0.0161	0.0029	1.52	0.24
1	11	-0.5058	3.2446	-0.0061	0.0086	0.56	0.63
1	41	8.7802	-16.5817	-0.0033	-0.0089	0.79	1.28
1	42	5.3029	8.1680	-0.0092	0.0032	0.88	0.27
1	101	-3.7705	-4.9910	0.0327	-0.0193	2.86	1.45
1	102	4.3259	-5.0001	-0.0176	-0.0156	1.42	1.15
1	103	-3.9022	9.5017	-0.0024	0.0102	0.19	0.77
1	104	3.9595	10.3228	-0.0280	-0.0011	2.18	0.09
					0.0448	0.0352	

Maximum in vx:	0.0327	at point:	101
Maximum in vy:	-0.0226	at point:	1

To every photo the adjusted image coordinates are given in this section of the result file. The information exposed themselves near the image and point number together:

x, y **:** the adjusted image coordinates, i.e. the correction were applied to the measured values
vx, vy **:** the coordinate corrections in the unit of the image coordinates (mostly mm)
Tx, Ty **:** test statistics from the outlier test

The faulty observations which have still remained in the data material are marked at their test statistics accordingly. If for the bundle adjustment, however, no outlier test was switched on (cf. chapter 10), the columns below Tx and Ty are empty.

Besides this point-related information the following is determined for every image:

- The coordinate measurement accuracy of a photo
  0.0448 0.0352
  using the sum of squared corrections, in each case for x and y.
- At last, for each image the points with the largest correction in x resp. y are given.

Maximum in vx: 0.0327 with point: 101
Maximum in vy: -0.0226 with point: 1

11.2.10 Image Lines

```
-------------------------------------------------------
---Image Lines------------------------------------------
-------------------------------------------------------
```

Image	Lin	a	b	v1	v2	Ta	Tb	
			mm	µm	µm			
-----	-----	--------	-----	----	----	----	-----	----

2	LIN01	0.01518	-4.902	18.0	23.5	0.05	0.26
2	LIN04	-0.07768	5.430	31.4	29.7	0.18	0.04
2	LIN05	0.03735	-3.776	15.8	11.3	0.00	0.23
2	LIN06	0.05437	-2.940	14.2	11.7	0.03	0.20
2	LIN08	-0.04902	4.658	0.7	14.7	0.18	0.02

0.0022 with line: maximum LIN08 in vb:-0.0152 with line: LIN01

The individual columns for each image have the following meaning:

a, b **:** this are the adjusted image line parameters
v1, v2 **:** the auxiliary corrections which are given instead of va and vb. The auxiliary corrections are the shortest distance to the image line if one projects the end-points of the space line into the image. They can be geometrically more easily interpreted as against va and vb.
Ta, Tb : test statistics of the outlier test

In addition, the respective maxima among the corrections are compiled at the end of every section. These concerns the corrections (va, vb) of the image line parameters, not the auxiliary corrections.

11.2.11 Additional Observations

```
----------------------------------------------------------
---Additional Observations--------------------------------
----------------------------------------------------------
Type      From     To        Observ.  V         ri        T
--------------------------------------------------
11:       Dist     8         9        4.0638  -0.0362  0.9005   2.34
```

Provided that additional observations have been introduced in the bundle adjustment, these are given in a section. Except the information to the observation, the following dimensions are still calculated:

v **:** the correction of the respective observation
ri **:** the redundancy component of the observation
T **:** the test statistics of the outlier test

This information is analogous to observed x or y coordinates of an image point.

11.2.12 Image Measurement Accuracy and Variance Components

```
-------------------------------------------------------------------
---Image measurement accuracy and variance components------------
-------------------------------------------------------------------
```

This section is made up of three subranges:

11.2.12.1 Accuracy of Single Photo, and Redundancy Components

Point: Image	sx	sy	sx	rx	ry
1	0.0217	0.0177	5.286	6.925	
2	0.0130	0.0128	5.918	5.887	
3	0.0154	0.0140	8.474	9.123	
4	0.0133	0.0109	8.036	8.534	
5	0.0182	0.0141	6.824	8.495	
6	0.0175	0.0155	9.194	9,320	
7	0.0243	0.0154	8.177	7.934	
8	0.0168	0.0120	10.884	10.954	
9	0.0170	0.0166	7.102	7.773	
10	0.0144	0.0192	6.183	9.036	
-------	-------	-------	-------	------	

D/S	0.0172	0.0148	76.078	83,980	
LIN: Image		sa	sb	ra	rb
----------	----------	----------	----------	---------	
2	0.0019	0.0142	3.018	2.838	
5	0.0018	0.0153	0.872	1.055	
10	0.0019	0.0132	1.127	1.031	
-------	-------	-------	-------	------	
D/S	0.0018	0.0142	5.018	4.924	
Whole redundancy ri			170,000		
Whole redundancy n-u			170		

In this section are listed in the columns sx, sy and sa, sb the image-related measurement accuracy – namely after the adjustment – as well as the proportionate redundancies rx, ry and ra, rb. Both are listed separately for point and line observations.

The whole redundancy is determined once ("theoretically") from the number of the unknowns and observations and once ("practically") from the bundle adjustment.

Whole redundancy ri	170.000
Whole redundancy n-u	170

Both values must agree. If this is not the case, the whole adjustment result is useless. As a cause for a difference are possible:

- There are still – very large – outliers in the observations
- or the adjustment system shows a so-called rank defect. A rank defect is, for example if only one control point is available in the bundle adjustment for the datum definition; in this case the image mosaic is not fixed to rotations and scale and the whole redundancy as sum of the redundancy components shows a deficit.

11.2.12.2 Variance Factors

Point :		Variance Factors			Standard Deviations	
		of x	of y		of x	of y
------------------------------------			-------------------			
Last used		1.0000	1.0000	and	0.0100	0.0100
Recommended	1.	1.7479	1.4972	and	0.0100	0.0100
Or	2.	1.0000	1.0000	and	0.0175	0.0150
LIN :		Variance Factors			Standard Deviations	
		of a	of b		of a	of b
------------------------------------			-------------------			
Last used		1.0000	1.0000	and	0.0100	0.0500
Recommended	1.	0.1843	0.2845	and	0.0100	0.0500
Or	2.	1.0000	1.0000	and	0.0018	0.0142

The accuracy ratio sx:sy is sufficiently determined: 10:9.9

Here separated after point and line observations information is given about the variance components (variance factors). The following statements relate to the image point coordinates x and y as observations, however, they apply analogously to the image line parameters a and b.

The weights of the image observations are derived as is known from the set a priori standard deviations. At this, regarding the primary calculation goal – the determination of the orientation parameters – only the ratio of the standard deviations σ_x and σ_y does matter, not their absolute value.

Before the beginning of the bundle adjustment the mentioned ratio and thus the weighting can be controlled on the one hand by the variance factors (see chapter 10). On the other hand, likewise the standard deviations of the image points could be changed uniformly. Just notice that both definitions influence themselves mutually. I.e. only one of both actions is to be taken.

The above file output are to be interpreted before this background as follows:

The line

Last used	1.0000	1.0000	and	0.0100	0.0100

states the values on which the bundle adjustment was calculated. In this example the a priori standard deviation of the coordinates is 10 μm each and the variance factors remain unchanged, i.e. the weights for x and y coordinates are equal.

Now in the other lines suggestions are made for the adequate weighting. Either the variance factors or the standard deviations are adapted (uniformly in all images):

1. Variance Factors

Recommended	1.	1.7479	1.4972	and	0.0100	0.0100

If the old standard deviations should be maintained, the variance factors are to be placed for x and y on 1.7479 or 1.4972.

2. Standard Deviations

or	2.	1.0000	1.0000	and	0.0175	0.0150

Or alternatively one could set the standard deviations of the images uniformly to 7.5 or 15.0 μm what has (with unchanged variance factors) the same effect on the weighting.

The adaptation of variance factors or standard deviations causes at first only that the (renewed) bundle adjustment is calculated on the “true” measurement accuracy. On the orientation result this only one slight influence has.

In the present example the new calculation with the suggested variance factors would bring no change because the ratio of the standard deviations is determined already sufficiently. This is also noted clear-written in the last line of the section:

The accuracy ratio sx:sy is sufficiently determined: 10:9.9

If this is not the case, this message appears instead:

The accuracy ratio is not sufficiently determined yet!

Whether one carries out in this case the bundle adjustment with the recommended weight changes once more, depends on the purpose of the photogrammetric survey:

- Is to be measured very precisely, one cannot but calculate with new weights. Notice that the adaptation must occur iteratively in several flows. Only if the suggested variance factors (or standard deviations) change no more, the “true” weight ratio is determined.

  The automatic estimation of variance components (chapter 10) executes this iterative process automatically.
- In most cases the bundle adjustment need not be repeated, even if the message about the

insufficient determination of the accuracy ratio shows up. Only if the "true" ratio diverges very strongly from the set ones (1:2 or even 1:3 and more) a re-weighting should be done.

11.2.12.3 Global Standard Deviations

Standard Dev.	:	so	sx	sy	sa	sb
--------------	------	------	------	------	------	
a priori	:	0.0200	0.0100	0.0100	0.0100	0.0500
a posteriori	:	0.0315	0.0175	0.0150	0.0018	0.0142

s_0: Standard deviation of unit weight

$s_{x,y}$: standard deviation of the image points (of all images)

$s_{a,b}$: standard deviation of the image lines (of all images)

The standard deviations a priori (before the adjustment) and a posteriori (after the adjustment) are distinguished in the following quantities:

These quantities can be understood as a global measurement accuracy, which give an impression of the altogether achieved accuracy. If the standard deviation of unit weight is after the adjustment (nearly) identically to the value a priori, this says that the set standard deviations a priori come very close to the actual measurement accuracies. However, for the orientation result less the absolute size, rather than the ratio of the standard deviations is important.

11.2.13 Outliers

---Outliers per Flow--

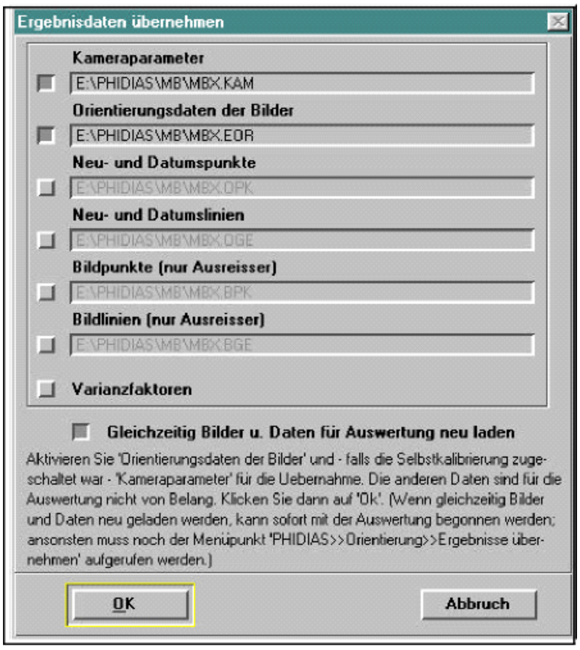
Item	Number	Image	No.	Type	vx/va	vy/vb
-----	------	-----	---	------	-------	-------
1.	2	5	1	Point	0.3181	-0.0079
2.	1	7	1	Point	-0.0833	-0.0059
3.	1	7	40	Point	-0.0449	0.0003

At the end of the output file becomes about the outliers who have discovered within the scope of the bundle adjustment and have been eliminated, reports.

In the column Number the total number of the outliers discovered per flow is given. How many of them have been actually eliminated, is seen from the information behind that. Per flow the eliminated points or lines are listed. The corrections give a first impression, how large the error is in each case.

11.3 Accept Orientation Results for Processing

On clicking the button *Accept ...* appears the following dialog in which the result data can be accepted for processing.



Dialogfeld zur Übernahme der Orientierungsergebnisse

Dialog box to accept the orientation results

Whether and which data are accepted is set with the switches (yes / no) on the left. In detail we have:

1. **Camera data,** thus the camera constant, principal point coordinates as well as the distortion parameters so far as they are determined.

2. **Orientation data,** i.e. the station coordinates and the image rotations of every photo.

3. The adjusted **object point coordinates** are set in place of the approximate values. This makes sense, for instance, if the image orientation is to be redone with improved object point coordinates.

4. The same applies to the object line data.

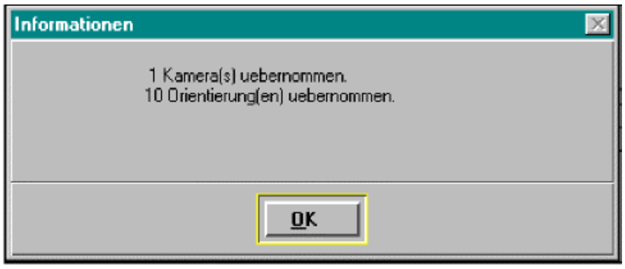
5. The blundered image observation can be inactivated in the BPK file and BGE file. Then these **outliers** would be ignored in a recalculation.

6. The variance components estimated in the adjustment of the image coordinates can be written into the control file for the bundle adjustment. With that the weights of the image observations are changed.

At last there is the switch *Reload Images and Data for Processing*. This switch has its meaning in context with the integration in PHIDIAS. If the switch is activated, the suitable data are reloaded directly after the results are accepted, so that the photogrammetric processing can begin immediately. In this case the results need not be re-accepted in PHIDIAS (see the also manual for the image evaluation).

By default only the switches for the camera data and orientation data are set to ‘Yes’ because only these are for the photogrammetric processing of importance. The remaining data are required only in rare cases.

With *OK*, the extraction process begins. The program searches in the result file for the relevant results and writes them into the suitable file. After execution it is reported about the number of the accepted data, like in the following example:



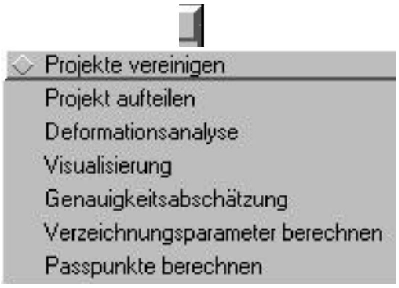
Display after acceptance of the camera parameters and orientation parameters

To make sure whether the data have been accepted correctly, the updated files can be viewed with *Edit Data*. The orientation parameters of the photos are in the EOR file and the camera data are in the KAM file.

With the acceptance of the orientation data and camera data the prerequisites for the photogrammetric processing of the measuring images are created in principle.

12. Additional Programs

Under the button *Additional Programs* different utility programs are available which are more or less closely connected to the image orientation. The option switch serves to select the respective utility program.



Overview to the utility programs

In detail the following operations can be done:

I. If two or more projects have been processed at first independently of each other, it is perhaps desired to merge them. The united image mosaic can then finally be oriented as a whole **(merge projects,** chapter 12.1).

II. To a certain extent as a counterpart of the project merger projects can be also separated in two smaller ones. This is meaningful, for example, for very big image mosaics which have proven afterwards to be badly to handle **(split project**, chapter 12.2).

III. With the tool of the bundle adjustment highly accurate coordinates of object points, among other things, can be determined, provided that the essential conditions for a photogrammetric precision measurement are kept with regard to photo arrangement, photo scale, etc. Should an object be examined for temporal deformations, it provides to do two or more photogrammetric surveys at different time (epochs). Then the appearing coordinate changes can be checked within the deformation analysis on significance **(deformation analysis**, chapter 12.3).

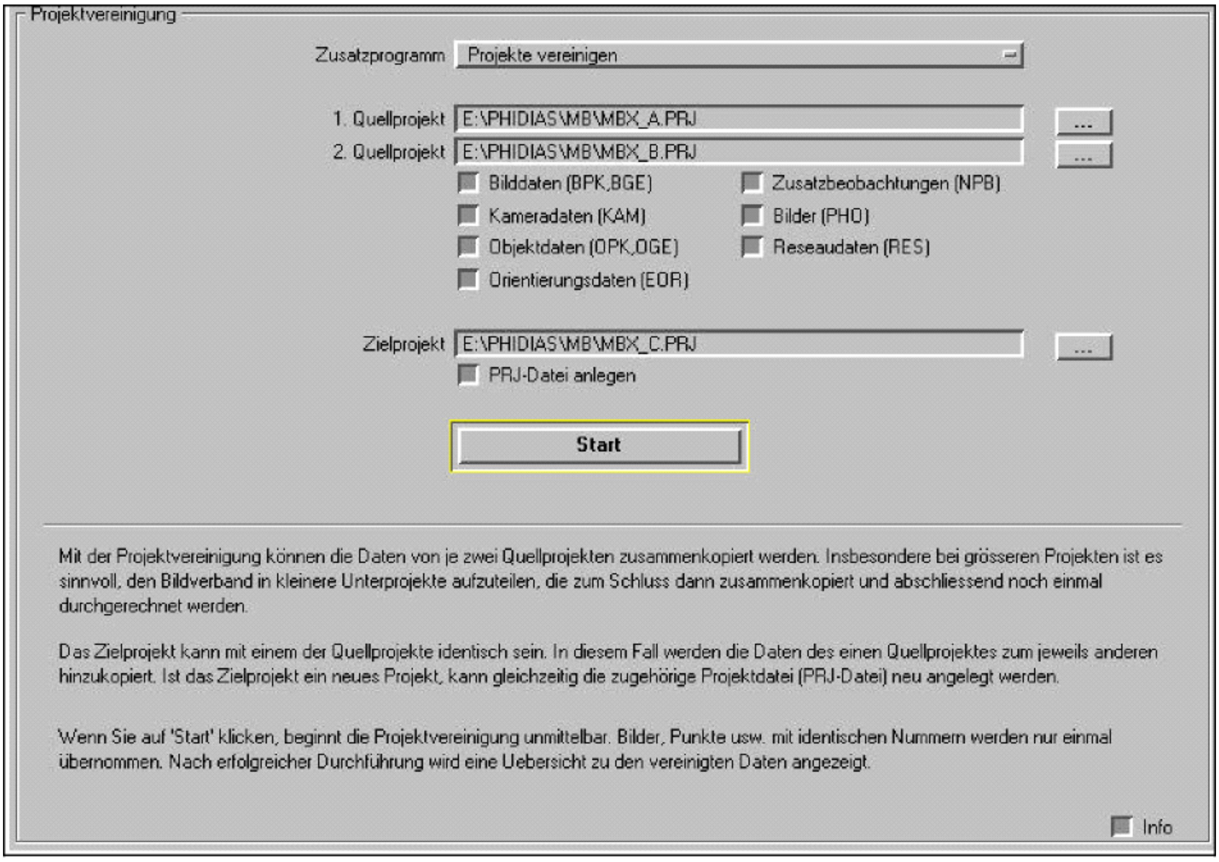
IV. To get an overview of the exposure constellation of the project, the object points and the photos can be shown graphically **(visualization**, chapter 12.4).

V. Every image orientation succeeds with a more or less high accuracy which depends on a lot of factors like image scale, exposure geometry, image point distribution etc. How accurate one can measure now in the processing, can be estimated by error propagation **(accuracy evaluation**, chapter 12.5).

VI. In of the image orientation the radial-symmetrical distortion is taken into account in the form of polynomial coefficients A_1 and A_2 (perhaps additionally A_3). However, in some cases only single measuring values are determined with the camera calibration as distortion data. Nevertheless, the equivalent distortion polynomial can be reconstructed from these single values with sufficient accuracy **(calculate distortion parameters**, chapter 12.6).

VII. In many cases for the processing of a project are at least some few control points measured, because these often facilitate the achievement of the orientation. Then the control points usually are surveyed on the basis of tachymetric observations like directions, zenith angles and distances as well as, perhaps, leveled level differences. Then the calculation of the point coordinates can be done very accurately, using adjustment techniques, by the module *PAB3D* which processes the mentioned observation types **(calculate control points**, chapter 12.7).

12.1 Merge Projects



An occasion for the union of at first independent projects can be given for different reasons. Thus it is advisable to the example with bigger projects (more than 50-60 images) to set up in the beginning two or several smaller projects which are processed separately first everybody for themselves separately. The blunder detection more simply develops so as a rule. Later then the Sub projects are united and afterwards are compensated once more, so that a homogeneous image mosaic comes into being. Or another example is if a older project should be combined with a newer one which has been oriented at first independent on former one.

With sufficient knowledge of the single data formats (see chapter 13) can become the necessary project data basically under aid of an usual editor copied together. The suitable files store the data in the ASCII format, so that from this side from no problems might appear. Nevertheless, more comfortably and more certainly in regard on the guarantee of the data consistency is the use of the provided utility program.

The dialog elements for the project merger consist as follows:

1. In the course of the project merger **1st and a 2nd source project** are expected whose data copied together should become. The source projects must exist, otherwise the program breaks off. The identification of the source projects happens about the respective project file (PRJ file).

Among the rest in the project files the file names become for the image coordinates (BPK), camera data (KAM) etc. defined. In most cases best of all if these files the same names sit like the project, only the name extension (extension) is different. Nevertheless, if the default names are not used, the program looks with the project merger for the relevant files. If necessary the names of the involved files are to be checked (e.g., under the menu item *automatic).*

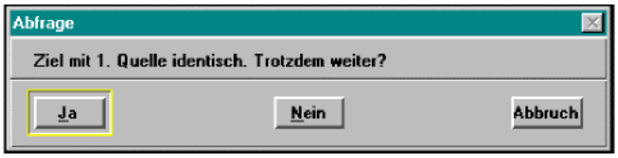
2. For the image orientation and image evaluation are a total of 7 different **data types** of importance:

    - Image data (BPK file and/or BGE file)
    - Camera data (KAM file)
    - Object data (OPK file and/or OGE file)
    - Orientation records (EOR file)
    - Additional observations (NPB file)
    - Path and name of the images and transformation data (PHO file)
    - Réseau data (RES file)

    About the suitable (Yes / No) *switches* it is fixed which become of these data copied together.

3. Analogously to the source data the **destination project** about the accompanying project file (PRJ file) is defined. The destination project need not exist. If this is the case, new files are created for the united data whose names are derived from the name of the destination project (e.g. *ziel.bpk, ziel.kam* etc.). If the destination project already exists, available data are headlined, perhaps, without additional further inquiry.

    The name of the destination project can be identical with one of both source projects. Then in this case the summarized data are stored in the suitable source project. If the 1st source project is given, for example, as a purpose, the program adds the data of the 2nd source project to the first one. However, the respective source project is not headlined automatically, but appears at first a relevant inquiry which the user with *Yes* must confirm.



Confirmation inquiry, if the name of the destination project is identical with one of the source projects.

1. If the destination project does not exist yet, the user can determine whether the accompanying project file (PRJ file) of the united data is recreated. Moreover the accompanying switch on is to be placed *Yes*. If the destination project exists, this switch has no function.

With start both given source projects become according to the defaults copied together. On this occasion, apply the following principles:

- Thereupon the data are examined whether records double if necessary are. If, for instance, in the camera file (KAM) of the 2nd partial project same camera race like in the 1st source project exist, these are not added once more. The identical applies to the image data (BPK, BGE), object data (OPK, OGE) and orientation data (EOR) as well as the images (PHO) and réseau data (RES). Only the additional observations (NPB) become without additional examination copied together. However, the investigation on record identity limits itself only to the identification number, not to the comparison of the numerical data. With the image coordinates the image numbers, with the camera data are this the camera numbers, with the object points their point numbers and with the orientation data only the image numbers.

- In connection with the examination on double records it plays under circumstances a role which project is declared as first and which as the second source. The program prefers the 1st source project, out of this i.e. the data are written anyway in the destination files. If now double records are found, the values from the 2nd source project remain in each case disregarded.

- If a single data file does not exist or is not found, the program not breaks off, but this simply ignores. As an example the object point file (OPK) of the 2nd source project exists, nevertheless, that of the first one is missing. In this case only the object coordinates of the 2nd source project are written in the destination file. If both OPK files were missing, the destination file remained empty.

After successful realization of the project merger a list of the number of summarized records is displayed on the screen.

Daten vereinigt unter E:\PHIDIAS\MB\MBX_C.PRJ

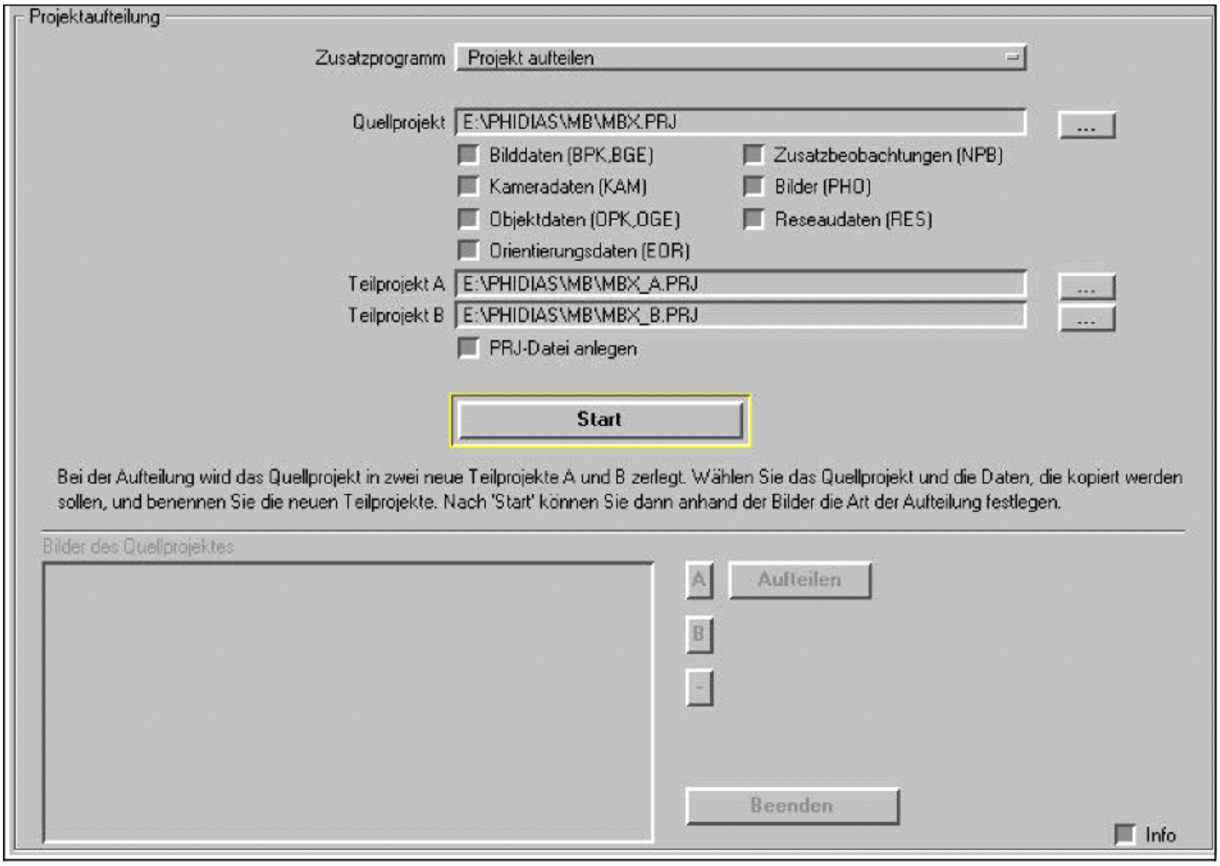
		1. Quelle	2. Quelle	Ziel
Bildpunkte	BPK :	108	55	163
Bildlinien	BGE :	0	0	0
Kameradaten	KAM :	1	0	1
Objektpunkte	OPK :	37	0	37
Objektlinien	OGE :	0	0	0
Orientierungsdaten	EOR :	7	3	10
Zusatzbeobachtungen	NPB :	0	0	0
Bilder	PHO :	0	0	0
Reseaudaten	RES :	0	0	0

(Projektdatei wurde neu angelegt.)

Screen display when project merger is done

In the end, by operating *the OK,* key this program part ends.

12.2 Split Project



The decomposition of projects in smaller partial projects can be recommended, for example if the treatment has turned out as very difficult. Often it helps when a subset is established in images with which one gets to a success. Then this base amount serves as a source platform for the gradually adding of other images. Another example can be the temporally moved treatment of a large-scale project. It then makes sense sometimes to take over some images of the older project into the new image mosaic at the continuation place.

The dialog elements for the project subdivision are identical partly with those from the previous chapter. Therefore, the following executions can collect themselves a little shorter.

1. The project starts from an available **partial project** which is identified here by the name of the project file. In the PRJ file the references to the concrete data stand as everybody knows like camera data, image points etc...

2. **The data types** (image points, object points, etc.) are same like with the project unification (chapter 12.1). With the suitable switches some of them can be excluded if necessary.

3. The projects are separated basically in two new ones. That's why two **destination projects** must be defined. These partial projects are called in the other course shortly with A and B.

4. If the new partial projects do not exist yet, the accompanying project files (PRJ file) should be constructed as a rule. Moreover serves the relevant switch *PRJ file put in*.

As soon as the button *Start* is pressed, the program reads first the data of the given partial project. Now afterwards the user must fix which images should get in project A and which in project B.

Bilder des Quellprojektes

A	Bild	1	mit	15+0	Beob.
A	Bild	2	mit	13+9	Beob.
A	Bild	3	mit	15+0	Beob.
A	Bild	4	mit	15+0	Beob.
A	Bild	5	mit	17+11	Beob.
B	Bild	6	mit	16+0	Beob.
B	Bild	7	mit	21+0	Beob.
B	Bild	8	mit	18+0	Beob.
B	Bild	9	mit	16+0	Beob.
B	Bild	10	mit	17+9	Beob.

The list with the images of the partial project. Image 2 contains e.g. 15 image points and 9 image lines as measured observations.

The subdivision of the projects happens using the images. Because the user fixes which images should get in which partial projects, the accompanying object points, image observations, orientation data arise automatically etc...

The marking occurs with the A-or B keys of the keyboard. an image can be also excluded completely by the consideration. Moreover serves '-' key. Alternatively to the keyboard the corresponding buttons can be also used.

The program function ' split project' can be also be used for completely copying a whole project. For this all images are simply marked with the same letter A or B. Then the data are copied identically to the sub-project A or B.

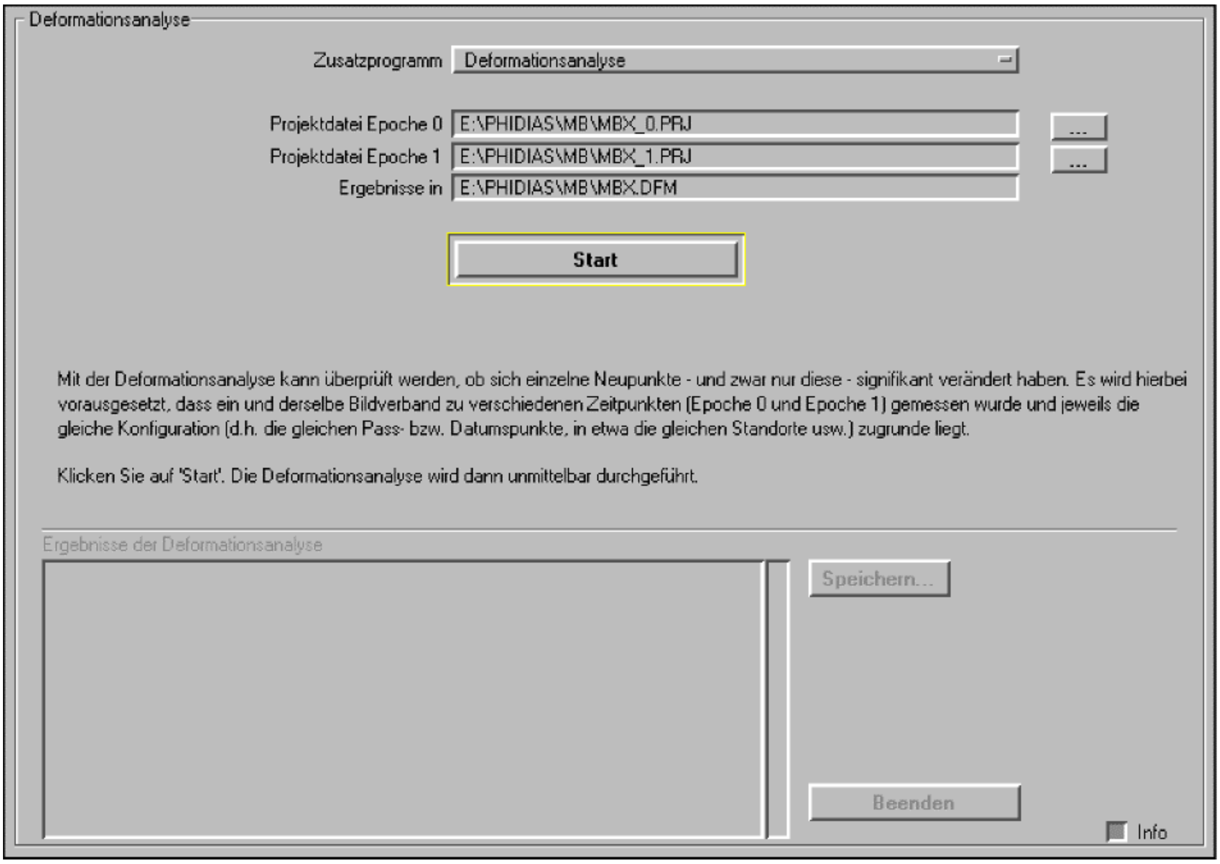
```
Quellprojekt E:\PHIDIAS\MB\MBX.PRJ wurde aufgeteilt.
Teilprojekt A : E:\PHIDIAS\MB\MBX_A.PRJ  (PRJ-Datei wurde neu angelegt)
Teilprojekt B : E:\PHIDIAS\MB\MBX_B.PRJ  (PRJ-Datei wurde neu angelegt)

                             Teilprojekt A  Teilprojekt B
-----------------------------------------------------------
Bildpunkte            BPK :              75             88
Bildlinien            BGE :              20              9
Kameradaten           KAM :               1              1
Objektpunkte          OPK :              20             21
Objektlinien          OGE :              11              9
Orientierungsdaten    BPK :               5              5
Zusatzbeobachtungen   NPK :               0              0
Bilder                PHO :               0              0
Reseaudaten           RES :               0              0
-----------------------------------------------------------
```

Log of successful project subdivision

If the allocation of the images is done, the actual split is executed. In addition the button *Split* must be clicked. After successful execution finally the program logs this process, i.e. on the screen small statistics about the number of the copied data are given.

At last, this program segment is finished by clicking *Finish*.

12.3 Deformation Analysis



The primary purpose of an image orientation usually is the determination of the orientation data, thus of station coordinates and camera rotations for the processing. Beyond it, with the bundle adjustment highly accurate object point coordinates can be also calculated, provided that the essential conditions for a photogrammetric precision measurement are kept. These conditions refer among other things to the optimum choice of the camera stations, so that a stable image mosaic is given, on the guarantee of a large enough image scale as well as on suitable actions for signalling the object points. Are higher accuracies wanted, the signalling is generally indispensasble. Under optimum conditions, in photogrammetric precision measurement relative precision from 1:30.000 and more (referred to the object dimensions) can basically be reached in that way. In particular if objects with a high point density are to be surveyed, photogrammetry provides as a suitable measuring technique.

Should the (temporal) deformations of an object be investigated, this assumes the highly accurate survey at two or several different times (epochs). In the further course it is assumed, that an image mosaic has been oriented at the epochs 0 and 1 independently. Every image mosaic is administered in the accompanying project file. Then the coordinates of the object points will differ generally more or less from each other. Now with the deformation analysis these coordinate differences can be investigated here whether they are significant or are based only on the natural measuring inaccuracies.

So that a comparison of both epochs leads to significant results, the following aspects are to be noticed:

- The image mosaics of the zero epochs and subsequent epochs must be identical concerning construction and configuration basically. This contains that the identical number are kept in photos and nearly identical camera stations. This measure has for the purpose of that the image mosaics with comparable basic precision are determined. Possible differences may be founded at least not in the geometrical constellation. If the standard deviations differ too strongly, the sensitivity of the deformation analysis suffers too much.

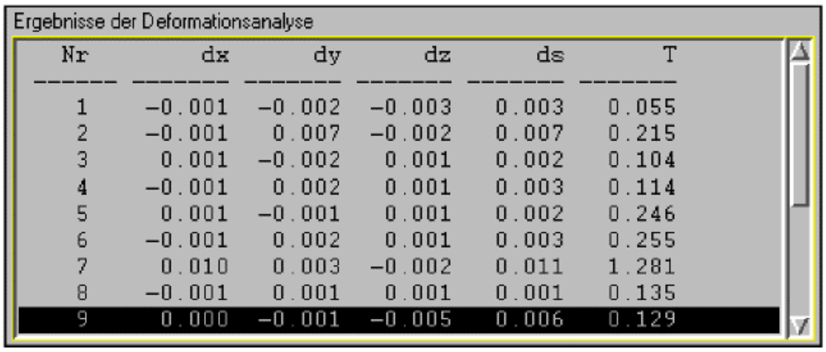
- For a significant deformation analysis must be available enough points to which with sufficient security immutability can be subordinated. For these stable points is to be shown consideration already by the planning of the deformation measurement. Then the datum of both image mosaics is to be fixed in each case using these stable points; anyway the datum definition should be identical with both epochs. The datum definition can occur either about invariable control points or about movable datum points in connection with the free network adjustment. It is important in both cases that in every epoch the same points are selected.

- Control points should be used as stable points only if one can assume quite certainly from the fact that these have been determined absolutely reliably and with higher coordinate precision. Otherwise it is advisable as a rule to calculate the image mosaics as a free network because the so possible pseudo-deformations which are founded in faulty control points are avoided. Then the datum of the free network is to be defined in both epochs on the base of the same object points. If, on this occasion, all object points are declared as datum points, one must be in the clear one that then only relative movements are determinable under the object points; and these are compensated if necessary still partly by the datum definition. That is why only the stable points should be used regularly as datum points. All probably variable object points are to be defined, however, as new points.

- In the deformation analysis the coordinates of the new points - namely only this - on significant changes are checked. On this occasion, the mathematical tools are the statistical hypothesis test of single points. (There the image mosaics independently of each other are compensated, however, must be neglected the covariances between the epochs.) A test statistics T is calculated on this occasion which is based on the F distribution. If the test statistics exceeds the – redundancy dependent – limit value, can a significant coordinate movement (deformation) be supposed. As a confidence level is employed in this context usually 5.0%. Into the hypothesis test enter, among other things, the standard deviations of unit weight (a posteriori). So that the epochs are comparable, therefore, the standard deviations a priori, thus the weight constant before the adjustment, must be identical at both image mosaics. If this is not the case, the hypothesis test possibly leads to misjudgments. It is even better if in each case a estimation of variance components is calculated. On this occasion, the program in the course of the bundles adjustment determines the “true” accuracy which applies to the respective image mosaic (cf. chapter 10).

For the *deformation analysis* the project names of the zero epoch and the subsequent epoch (epochs 0 and 1) must be given at first. In the deformation analysis exclusively the output files (out files) are used, there stands all required information. Then by clicking the button *Start* the investigation of the object points begins directly.

After successful realization the results of the deformation analysis are indicated in a list field.


Ergebnisse der Deformationsanalyse

Nr	dx	dy	dz	ds	T
1	-0.001	-0.002	-0.003	0.003	0.055
2	-0.001	0.007	-0.002	0.007	0.215
3	0.001	-0.002	0.001	0.002	0.104
4	-0.001	0.002	0.001	0.003	0.114
5	0.001	-0.001	0.001	0.002	0.246
6	-0.001	0.002	0.001	0.003	0.255
7	0.010	0.003	-0.002	0.011	1.281
8	-0.001	0.001	0.001	0.001	0.135
9	0.000	-0.001	-0.005	0.006	0.129

Display of the results from the deformation analysis

The following information is given for each object point (new point):

dx, dy, dz Coordinate differences between zero epoch and subsequent epoch of X, Y, and Z direction

ds Length of the spatial distance vector between the points of both epochs

T Test statistics T of the statistical hypothesis test; the fractile or limit value arises from the F distribution (confidence level α = 5.0 %), and the respective redundancy

Whenever the test statistics crosses t the limit value, a – within the confidence level – significant deformation can be assumed. Then the suitable lines are marked with an asterisk.

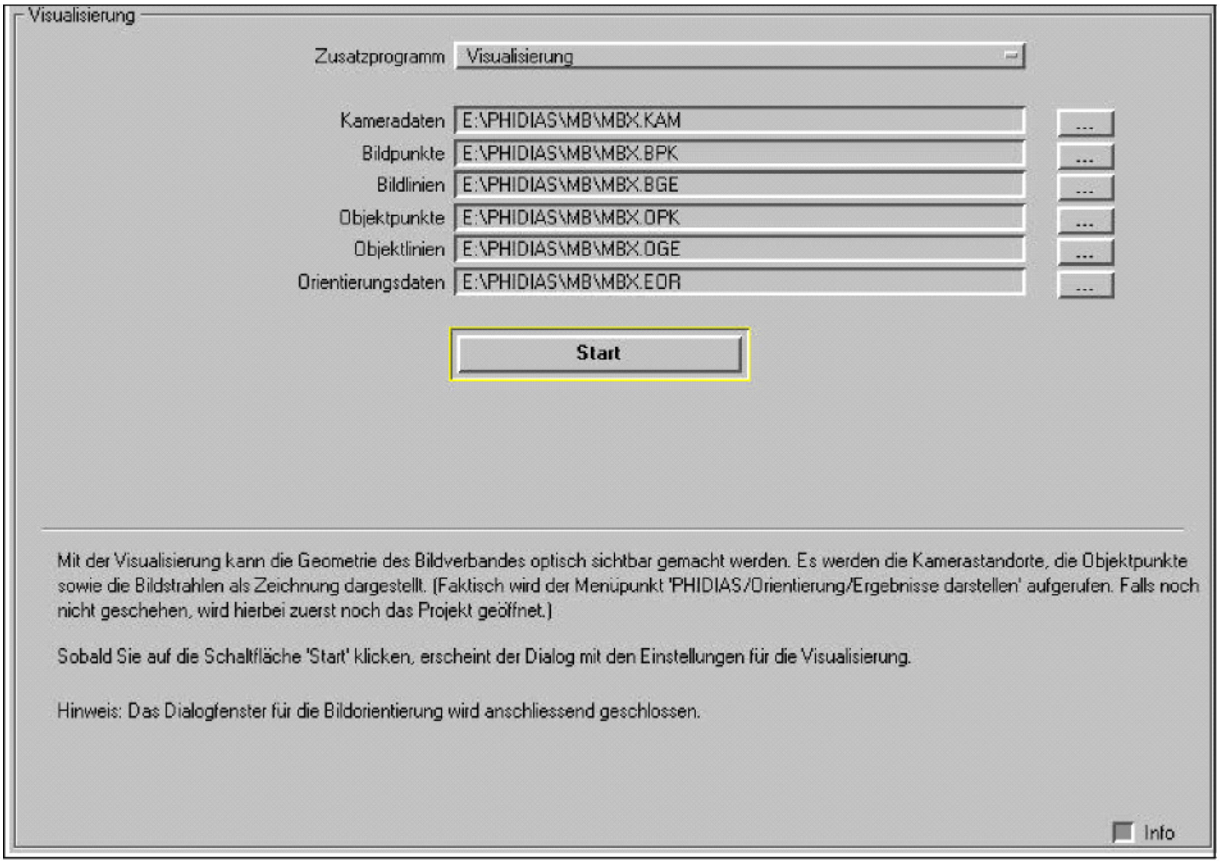
With the button *Save ...* the results are stored in a file. Then the program asks once more whether the results should be stored in the at the beginning defined file (as a rule, DFM file).

Interrogation for storing of the results of analysis

It is answered in this dialog box with *Yes*, in the end, results are stored.

The deformation analysis will leave by clicking the button *Finish* again. Now an inquiry concerning possible storing of results no more appears at this point.

12.4 Visualization



The geometrical constellation of an image mosaic can be illustrated by *visualization*. On this occasion, the following elements are shown:

1. **The object points** are shown as three-dimensional crosses. Every cross consists of three short lines which point in each case in the direction of the axes of coordinates. The point of all sides is equally well visible through this. The size of the crosses can be set.

2. **The image orientations** appear in the visualization graphic arts schematic outlines of the measuring images. Rotational and translational position in the object space as well as the representation of the exposure direction match, on this occasion, to the reality. Indeed, the photos present themselves to scale enlarged, so that a better being recognizable is given.

3. In the end, **the image rays** are still shown as the third object group. They arise as just lines between the object points and the photos.

Every group can be filed on own level or layer and be represented in different colors.

The dialog box with the settings to the visualization is opened by operating the button *Start*.

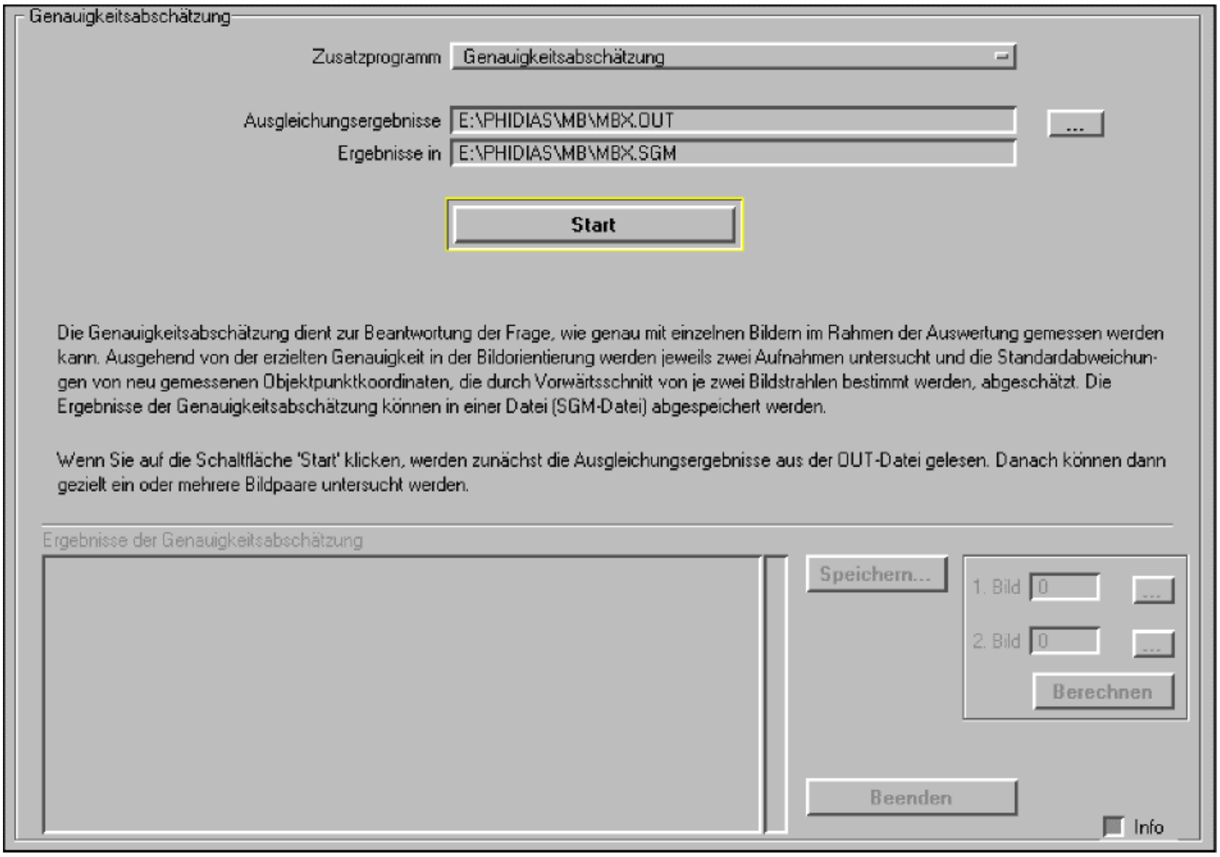
Settings for visualization

With clicking from *OK,* the before named elements are generated as a drawing. If, on this occasion, the switch *elements* is deactivated, these are not lasting, but disappear at the latest with the next zoom operation again.

□ the three-dimensional crosses to the representation of the object points are constructed geometrically accurately. The center of the cross symbol corresponds with the point coordinates. Provided that the exact coordinates from the bundle adjustment should be used, these must be extracted before from the result file and be written in the OPK file (see chapter 11).

The dialog box for the image orientation is automatically closed after the realization of the visualization, by the way, so that the sight at the drawing becomes free again.

12.5 Evaluation of Processing Accuracy



With the image orientation the prerequisites for the following photogrammetric processing are created. The orientation data can be calculated - like with every measuring task - only up to a certain accuracy what influeneces in turn the attainable accuracy of the image evaluation.

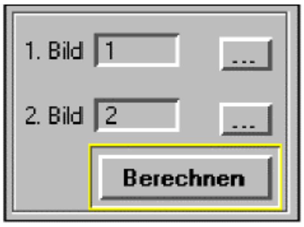
Beyond it, the accuracy depends decisively on the geometrical constellation of the photos used. Notice always that the photogrammetric processing principle is based on the spatial intersection of the image rays. Therefore, an unfavorable constellation is possibly with photos with nearly identical camera station because then so-called glancing intersection appear.

The processing accuracy of the current project can be estimated using the result data. As soon as the button *Start* is operated, the program loads all necessary information from the OUT file.

Basically a single image pair is examined always, i.e. the evaluation limits itself in two images. If it is measured during the later processing in three or more photos at the same moment, more accurate results can be expected regularly.

The program expects the input of the image numbers of the image pair to be examined *(1st image* and *2 image).* On this occasion, two possibilities exist basically:

1. A single image pair is examined by the concrete information of two (valid) image numbers.
2. Or – with the image number 0 – several image combinations are calculated equally.



Dialogelemente für die Genauigkeitsabschätzung

Dialog items for the accuracy evaluation

In the text fields *1st image* and *2 image* the suitable image numbers are to be put down in each case. If is clicked on the accompanying selection button, a dialog box with all available images opens for selecting.

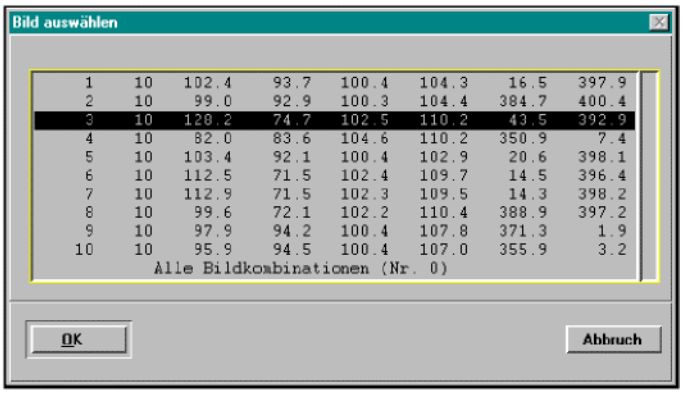
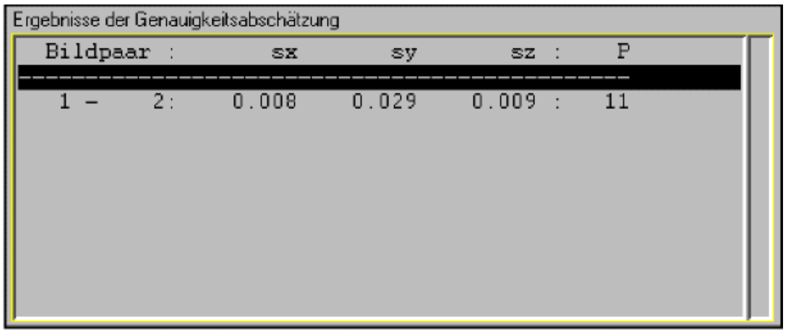


Bild für die Genauigkeitsabschätzung auswählen
Chose image for accuracy evaluation

The list of the images is complemented in this dialog box with another line which stands for the image number 0. This number represents "All image combinations ", i.e. in this case every image is examined.

12.5.1 Investigation of an Image Pair

If two valid numbers of an image pair have been defined, can with the button *Calculate* the accuracy evaluation be started. The result of the calculation is indicated in the result list and looks, for instance, as follows:



Respected processing accuracy of the image pair 1 - 2

In this example the processing accuracy of the image pair 1 - 2 was determined on the basis of 11 points, since to the common points from the image orientation. The accuracies (σ_x, σ_y, σ_z) are calculated for every coordinate separately. The information

$$sx = 0.008 \qquad sy = 0.029 \qquad sz = 0.009$$

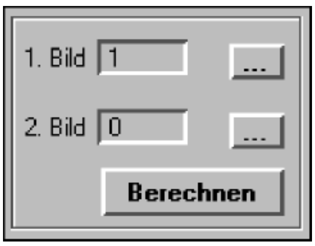
is to be interpreted so that by the photogrammetric processing using the named image pair a single object point is determinable in the space – on an average – with 0.8 to 2.9 cm (in the unit of the object points).

The figures are derived on the basis of the error reproduction calculation and own with regard to their absolute height, nevertheless, only expressiveness causes because one more row of other factors (e.g., being recognizable of points, type of the point, position can influence the concrete processing accuracy in the image etc.) positively as well as negatively. If is measured, beyond it, in more than two photos at the same moment, the point determination is more precise as a rule also accordingly.

However, the accuracy values can be used anyway for comparative considerations. Badly configured image pairs distinguish themselves by unusual high values for σ_x, σ_y and σ_z.

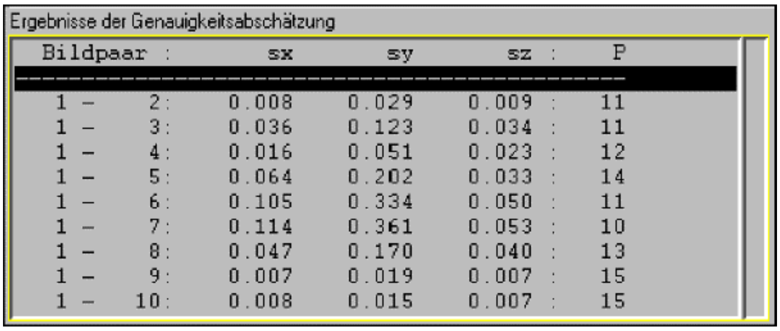
12.5.2 Investigation of Several Image Combinations

The information of the image number 0 causes the sequential calculation of all possible image pairs.



Calculation of several image combinations (number 0). Here image No. 1 is combined with all others.

The list window indicates according to the calculation the results from every generation of pairs:



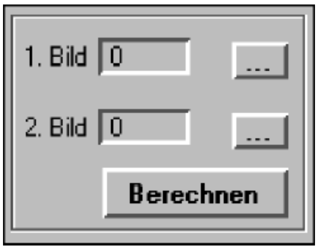
Ergebnisse der Genauigkeitsabschätzung

Bildpaar		sx	sy	sz	P
1 –	2:	0.008	0.029	0.009 :	11
1 –	3:	0.036	0.123	0.034 :	11
1 –	4:	0.016	0.051	0.023 :	12
1 –	5:	0.064	0.202	0.033 :	14
1 –	6:	0.105	0.334	0.050 :	11
1 –	7:	0.114	0.361	0.053 :	10
1 –	8:	0.047	0.170	0.040 :	13
1 –	9:	0.007	0.019	0.007 :	15
1 –	10:	0.008	0.015	0.007 :	15

List of the processing accuracies; here the image 1 was combined with all other images.

In addition to the accuracy information for each point coordinate the number of points used in the evaluation is indicated in the last line. The list window serves only to view the results and can be closed with **ESC** or **enter** again.

If both image numbers are specified in the start mask with ‘0’, this signifies that every image is combined with everybody. Then the number of the image pairs to be calculated increases clearly and the result list is longer accordingly.



If the No. 0 is put down for both images, every image is combined with everybody.

12.5.3 Store Accuracy Evaluation

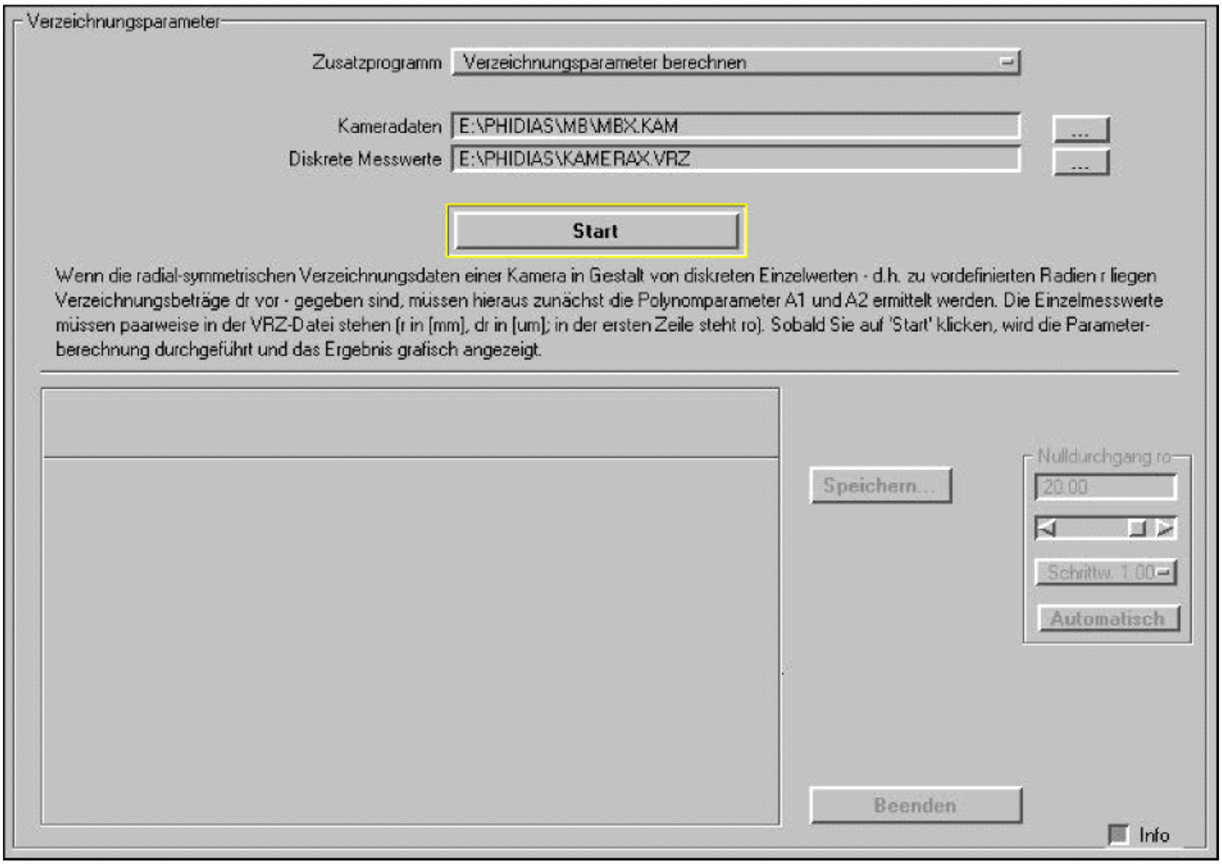
The currently indicated accuracy results can be stored in a file (SGM file) and be printed from now then, e.g. If the button *Save ...* is clicked, one more confirmation interrogation appears at first.

The name of the SGM file is set in the input dialog to the accuracy evaluation.

Inquiry before storing the accuracy evaluation

The calculation part of the accuracy evaluation will be left again with the *Finish* button. In this case there appears no further dialog.

12.6 Calculate Distortion Parameters



In the photogrammetric measuring practice often are cameras used which are delivered at purchase in calibrated state. Then the calibration data consist as a rule, along with the camera constant and the principal point coordinates, of the information about radial-symmetrical distortion (mostly called A_1 and A_2, perhaps additionally A_3). As distortion, the deviation from the accurate central perspective mapping of a point to the image plane is modeled and taken into account.

In some cases the distortion data are delivered by the camera manufacturer not directly in the form of the parameters A_i, but by giving discrete individual data. Thereby, for pre-defined, generally round radii, the corresponding distortion values dr are given (see the also example further below).

Among the additional programs there is the module *Calculate Distortion Parameters* with which the user can calculate from the discrete individual data, the parameters of the radial-symmetrical distortion – thus specifically the parameters A_1 and A_2. Using A_1 and A_2, the distortion is modeled by a polynomial, what satisfies practical requirements in most cases.

> Beyond that, there is the program VERZ.EXE, which is to be found on the installation media. This program is a genuine DOS program, i.e. it works perfectly only under the operating system MS DOS. The computer must therefore be booted under that operating system when the program is called. Moreover, the computer needs to be equipped with a VGA graphics card, what will be nowadays nearly always the case. A call with the option /? displays a short help for VERZ , which facilitates getting started.

The calculation of the distortion parameters from single measuring values expects the input of two files:

1. The **discrete measuring data** given by the camera manufacturer must be submitted to the program in a VRZ file (file name extension is arbitrarily). The user must record these values at first in the input file (ASCII) what is done most easily with an usual editor (e.g., EDIT of MS

DOS or NOTEPAD under Windows). The structure of the data must keep to a certain pattern what can look exemplarily as follows:

```
20.0

 2.0          57.0
 4.0          80.0
 6.0          99.0
 8.0         107.0
10.0         106.0
12.0          91.0
14.0          74.0
16.0          48.0
18.0          19.0
20.0          -9.0
22.0         -53.0
```

Example of the contents of an input file for calculation of the distortion parameters from discrete measuring values.

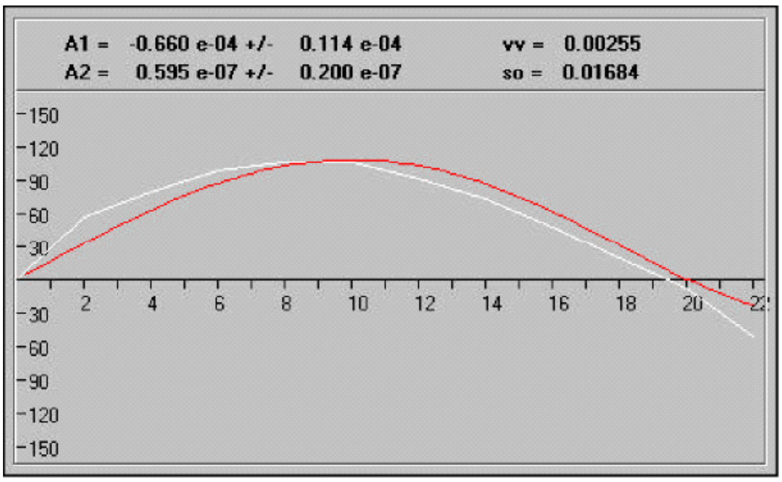
a) First the value $\mathbf{r_0}$ of the zero-crossing of the distortion curve is put down (here: 20.0). This number is only an initial value and can yet be changed in the further course. r_0 is given in the unit mm.

b) Thereafter follow the **value pairs** of the discrete individual data. In the preceding example distortion amounts were determined for the radii from 2 to 22 mm. At 8.0 mm, for instance, there is a distortion of 107.0 µm. Notice that the radii are to be given in mm, the distortion amounts, however, in the unit µm. The value pairs must be separated within a line only by a space, otherwise there apply no special format regulations.

An example file named VERZ.DAT should be on the installation media. The user can use this file as a copy template.

2. Moreover, a **camera file** (KAM file) can be named. Then the distortion parameters determined in the following course can be written in this file.

As soon as the button *Start* is clicked, the measuring values from the VRZ file are read and a first solution to the polynomial depending on the zero-crossing r_0 put down there is displayed.



Graphical display of the distortion polynomial

The current course of the calculated distortion curve is shown in a graph.

- The coordinate system consists of the x-(abscissae) and the y axis (ordinates). The x values are the radii **r** in mm and the y values are the distortion amounts **dr** in µm.
- In **white** color the **polygon of the distortion values** is shown. There, the discrete single values are connected by stright line segments. This polygon remains invariable.
- The **red** curve shows the currently calculated **distortion curve**. It should optimally fit the white polygon. Every time the zero-crossing r_0 gets changed (see below), the program recalculates the distortion curve immediately.
- In the upper area the current **distortion parameters** $\mathbf{A_1}$ and $\mathbf{A_2}$ are indicated together with their standard deviations. Like the distortion curve these values change if the zero-crossing r_0 is varied (see below). The parameters A_1 and A_2 are indicated always with the same exponential factor, i.e. A_1 with e-04 and A_2 with e-07.
- Moreover, the values **vv** and $\mathbf{s_0}$ are given. This are the **sum of the squares of the corrections** and the **error of unit of weight** from the adjustment. The distortion curve is determined by adjustment so that the sum of the square distances from the discrete single data is minimized.

12.6.1 Change Zero-crossing

The zero-crossing r_0 of the distortion, thus the position where the curve cuts the r axis, must generally be set fixed by the user, whereby the choice is free in principle. Nevertheless, the value should be chosen so that the distortion polynomial approximates the discrete single values as well as possible.

Because the zero-crossing r_0 is changeable by the user, the question arises now which value is most favorable. A possibility consists in setting the value r_0 so that the r axis is cut by the (red) distortion curve at about the same position like by the (white) polygon. This solution is absolutely suitable and is also sufficient for most applications.

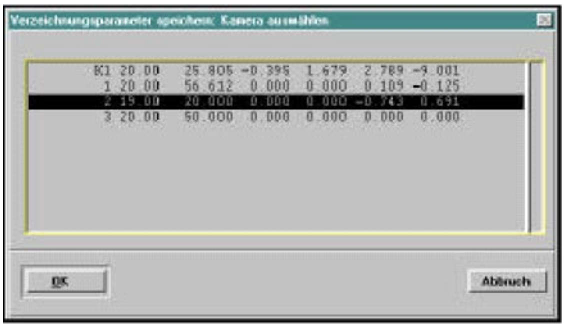
A more objective measure of a good approximation is the sum of squares of the errors (vv) from the polynomial adjustment, i.e. if that is smallest. A practicable possibility is in varying the value from r_0 purposefully while regarding the sum of squares vv which will increase or decrease as a function of r_0. The current value of r_0 can be changed either directly over the keyboard in the text field or gradually using the scroll bar. With the latter exists the possibility to adapt the increment to *1.0*, *0.1* or *0.01*.

The optimum zero-crossing r_0 can be found alternatively also by using the switch *automatic*. As soon as this button is pressed, the program looks for the position r_0 with the minimum error square sum vv and displays the result then. Because this position is in most cases an unround value, should at last a round value r_0 near this optimum be manually chosen; for the practical application this has generally no disadvantageous effects.

 At all chosing options is to notice that setting range of r_0 is limited upwards and downwards. The lower limit is always 1.0 mm, while the upper limit depends on the measuring values in the VRZ file. The maximum radius which is put down here also applies as an upper limit to the adjustable zero-crossing r_0 (in the example above this would be 22 mm).

12.6.2 Store Distortion Parameters

If a suitable polynomial was found, the corresponding parameters, i.e. the coefficients A_1 and A_2 together with the zero-crossing r_0, can be taken over into the camera file. For that the button *Save....* is of use.



Dialog while storing the distortion parameters in the camera file

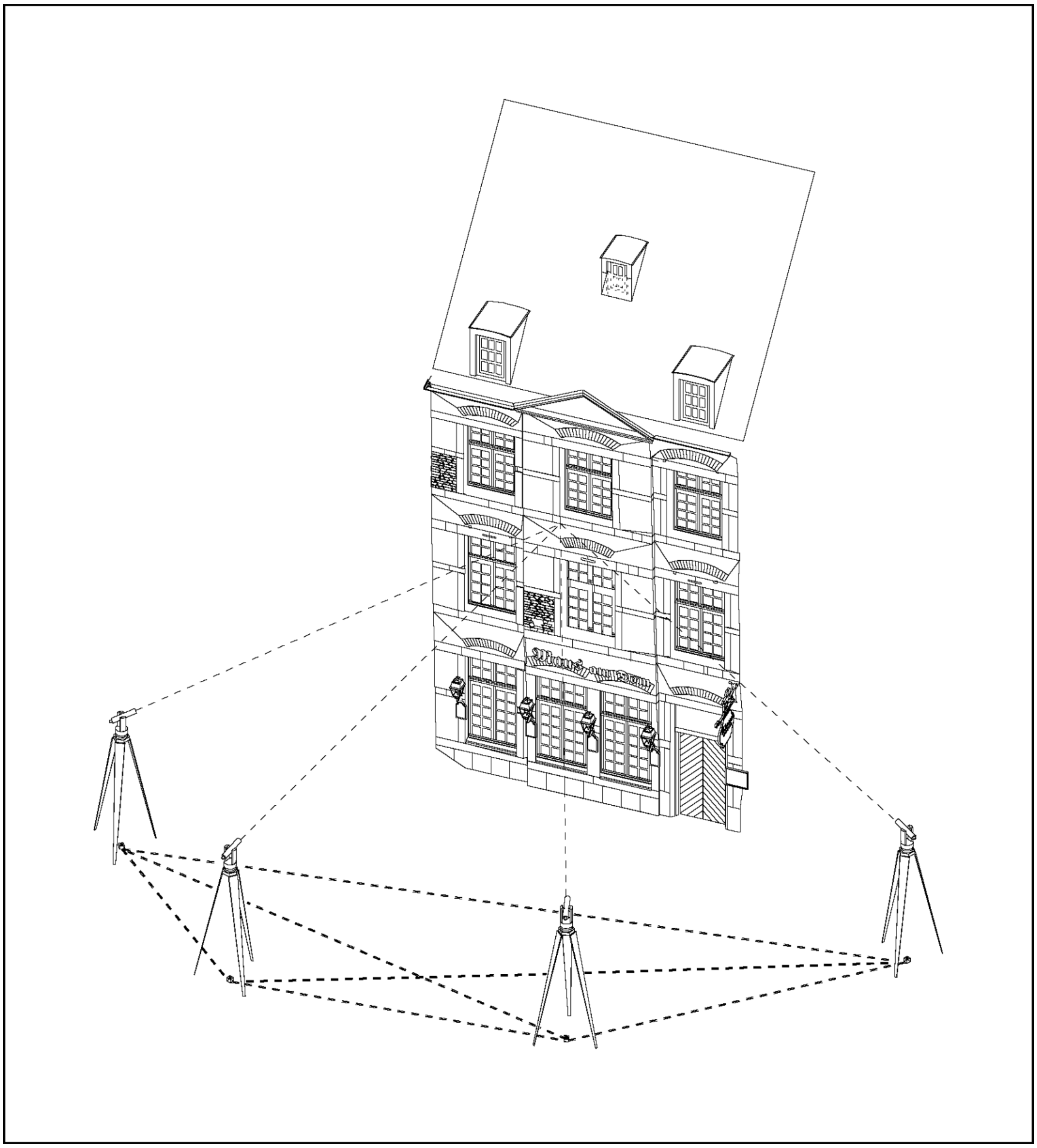
If available, the above-mentioned camera file is read and afterwards the list of the camera records in it is displayed. Now a desired camera can be selected here, and their parameters can be accepted with *OK*.

Mit dem Schalter *Beenden* wird dieser Programmabschnitt wieder verlassen.

12.7 Calculate Control Points

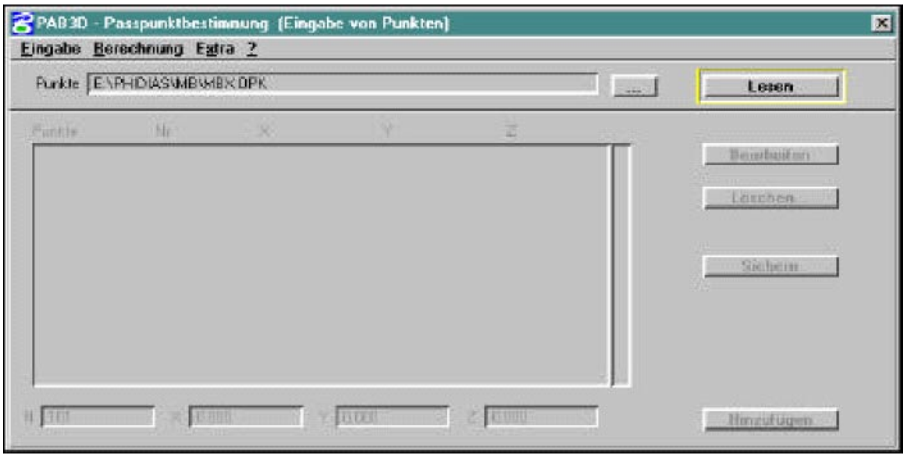
At many photogrammetric surveying tasks at least some few control points are determined in a conventional way, because this can facilitate the orientation above all. Generally selected points of the object are measured with a tachymeter, i.e. in the most general case quantities like horizontal directions, vertical angles as well as sloping distances or horizontal distances are measured. In cases, leveled level differences add to these observations. On the basis of these observations the three-dimensional coordinates of the control points can then be calculated, where as an almost always successful and effective principle the intersection is employed. At that the desired points are measured from several instrument stations. If the coordinates of these stations are known, which are determined in a preceding step if necessary, the control points can be calculated very accuratyly by intersection of the spatial observation rays.

The additional program described here enables the user to do the control point calculation program-based, using the tachymetric observation data mentioned before. The control point calculation takes place within an independent module, named **PAB3D.** Principally PAB3D has an independent file name management. I.e. the object point file (OPK) from the image orientation – for example – which plays a role also in the control point calculation is not used directly in PAB3D. Instead, usually an own OPK file is used here. Only if the switch *Take over File Name* is set, the currently given file names are at the call of PAB3D also used there at first. (Of course, other files can be used in further process again.)



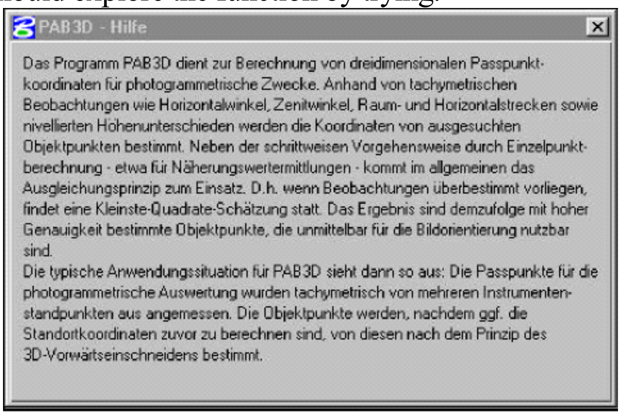
The picture shows the basic situation at the control point determination: the measurements are done, e.g., with a tachymeter, from several stations. These stations form in case together a small network which is connected by the mutual observations. In parallel the wanted control points are measured at the object, where each point – provided that only angles are observed – must be measured from at least 2 stations. As soon as the stations' X, Y and Z coordinates are at hand, the control points can be determined afterwards by three-dimensional intersection.

The module PAB3D is called by clicking the button *Start*. Then appears another dialog box *(PAB3D - control point determination)*.



The dialog box of PAB3D; here the dialog elements after the call of the menu item INPUT / POINTS.

PAB3D has a menu item *help.* As soon as this is activated, opens another dialog box in which exclusively help texts are displayed. The contents of the help field vary with the current situation in the program. Besides, the information displayed in each case is confined to the essential, in particular case the user should explore the function by trying.



The help field of PAB3D.

Because PAB3D has the mentioned help function, the description here is restricted to a short overview. This overview corresponds to the structure of the main menu of PAB3D, which besides the help consists of the following three items:

Input: Here data can be put in, edited or deleted. In addition it is possible to inactivate individual records by which a final deletion is avoided. Basically the object points (OPK) and the tachymetric observations (TBD) are to be discerned. Under ‘object points’ are administered in this context both the intrument stations as well as the actual target quantities, the control points at the object.

Calculation: after the input of the necessary data the calculation can take place. For this, one of two strategies can be chosen.

With the first one, comprising two steps, at first the coordinates of the tachymeter stations are determined, and afterwards from these the control points are calculated by intersection. During the first step – thus the determination of the instrument stations – can be further distinguished between the usual single point calculation and the three-dimensional network adjustment; where the single point method is to be used regularly to determine the approximate values for the network adjustment.

The second strategy, here called total adjustment, unites all sub-procedures of the first variant to one process. At this, no approximate values need to be determined by the user explicitly, this does the program. Moreover, the total adjustment has the option to search for errors among the observation data using additionally the L1 norm, besides the usual, statistical outlier test.

Extra: The menu item *Extra* provides different program functions. On the one hand, with *Settings*, so-called dimensioning parameter (e.g., maximum number of points) as well as the limit values at the error search can be set. Since else than in the total adjustment (see above) observation errors generally are assessed only in a simplified way using limit values, thus a statistical outlier search does not take place.

Beyond, there exists the possibility to convert the data from registering tachymeters automatically to the correct format of PAB3D. The expensive manual input can be dispensed with the data conversion.

13. Data Formats

Within the image orientation different files are used to store input, auxiliary and result data. All data like coordinates, rotation angles, camera parameters, etc., are stored exclusively in ASCII files and can be manipulated within the program according to requirements. Beyond this, it is in principle possible to edit single data with a usual editor (e.g., EDIT or NOTEPAD).

The single numbers are generally read format-free, that means only the correct order is of importance, not certain column positions. In the file for the three-dimensional object point coordinates – for instance – each point is stored with the elements point number, flag, X-, Y-and Z-coordinate. To read the points correctly it is only important that these figures stand in one line, in this order, and complete. All lines of the file which do not contain (at least) five numbers of which the first two are integers and the other three are floating-point numbers, will be ignored. Comment lines can be inserted into the files when required, they are not read and are harmless otherwise.

This section describes the different data formats and is laid out to serve as an information source for the different files, if the user prefers to do specific changes to the data by hand. The knowledge of which will not be necessary in most cases because an own menu item to edit the data is available (chapter 9). The single elements are explained in each case using an example record. The file name extensions given in parentheses are used under the operating system and are the defaults used.

13.1 File of Camera Data (.KAM)

3 1 15.0 35.000 -0.0213 0.1776 0.0010 0.0020 0.0030 0.0040 0.0050

3	Camera number
1	flag (1 = active, –1 = inactive)
15.0	r_0 - zero-crossing of the radial distortion curve
35.000	c - camera constant, in mm
-0.0213	x_h - principal point (x coordinate), in mm
0.1776	y_h - principal point (y coordinate), in mm
0.0010	A_1 – 1st coefficient of the radial distortion polynomial (10^{-4})
0.0020	A_2 – 2nd coefficient of the radial distortion polynomial (10^{-7})
0.0030	A_3 – 3rd coefficient of the radial distortion polynomial (10^{-10})
0.0040	B_1 – 1st coefficient of the tangential distortion polynomial (10^{-5})
0.0050	B_2 – 2nd coefficient of the tangential distortion polynomial (10^{-5})

In the file of the camera data stand after the named elements mostly still further numbers and specifications which refer to the fiducial mark definition and are needed in the course of photogrammetric processing.

So, for example, with 4 fiducial marks:

4 –18.000 12.000 18.000 12.000 18.000 -12.000 -18.000 -12.000

As the first number the number of the fiducial marks has to be stated. Then follow the coordinate pairs of the suitable marks.

However, if there is a regular réseau, the definition is:

R 7 5 5.5 5.5

The letter “R” means réseau. Then follow the number of the réseau crosses in x as well as in y direction (here 7 and 5). At last, the distances between the réseau crosses in x and in y direction are to be stated (here in each case 5.5 mm).

As third possibility a file can be given which contains the individual nominal coordinates of all available fiducial marks or réseau crosses.

F a:\phidias\mb\mbx.res

After the flag "F" (for file) path and name of the fiducial marks file follow.

13.2 File of Image Points (.BPK)

10 41 6 2.26106 13.27781 0.0200 0.0200

10	number of the image
41	number of the image point
6	flag (6 = active, –6 = inactive)
2.26106	measured x coordinate, in mm
13.27781	measured y coordinate, in mm
0.0200	measurement accuracy a priori x, in mm
0.0200	measurement accuracy a priori y, in mm

13.3 File of Image Lines (.BGE)

2 LIN03 16 3.70614 13.91358 3.77569 10.78764 0.010 0.050

2	number of the image
Lin03	number of the image line
16	flag (16 = active, –16 = inactive)
3.70614	x coordinate of the 1st end-point, in mm
13.91358	y coordinate of the 1st end-point, in mm
3.77569	x coordinate of the 2nd end-point, in mm
10.78764	y coordinate of the 2nd end-point, in mm
0,010	measurement accuracy a priori of parameter a, in 1
0,050	measurement accuracy a priori of parameter b, in mm

13.4 File of Camera Orientations (.EOR)

10 2 3 101.337 89.345 241.885 136.2287 -25.7780 385.3381

10	number of the image
2	flag (2 = active, –2 = inactive)
3	number of the assigned camera
101.337	X_0 - coordinate of the projection center
89.345	Y_0 - coordinate of the projection center
241.885	Z_0 - coordinate of the projection center
136.2287	ω – rotation angle around the x axis, in gon
-25.7780	φ - rotation angle around the y axis, in gon
385.3381	κ - rotation angle around the z axis, in gon

13.5 File of Object Points (.OPK)

41 7 881.734 531.331 106.003

41	point number
7	flag (7 = control point, 8 = new point, 9 = datum point, 10 = inactive)
881.734	X coordinate
531.331	Y coordinate
106.003	Z coordinate

13.6 File of Object Lines (.OGE)

LIN03 18 101.629 100.110 103.797 101.637 100.140 103.130

LIN03	line number
18	flag (17 = control line, 18 = new line, 19 = datum line, 20 = inactive)
101.629	X coordinate of the 1st end-point
100.110	Y coordinate of the 1st end-point
103.797	Z coordinate of the 1st end-point
101.637	X coordinate of the 2nd end-point
100.140	Y coordinate of the 2nd end-point
103.130	Z coordinate of the 2nd end-point

13.7 File of Non-photogrammetric Observations (.NPB)

11 43 65 12.36 0.001

11	flag for observation type (see below).
43	1. point no. or camera no. or image no. (depending on observation type)
65	2. point no. (optional, depending on observation type)
12.36	observation
0.001	observation accuracy

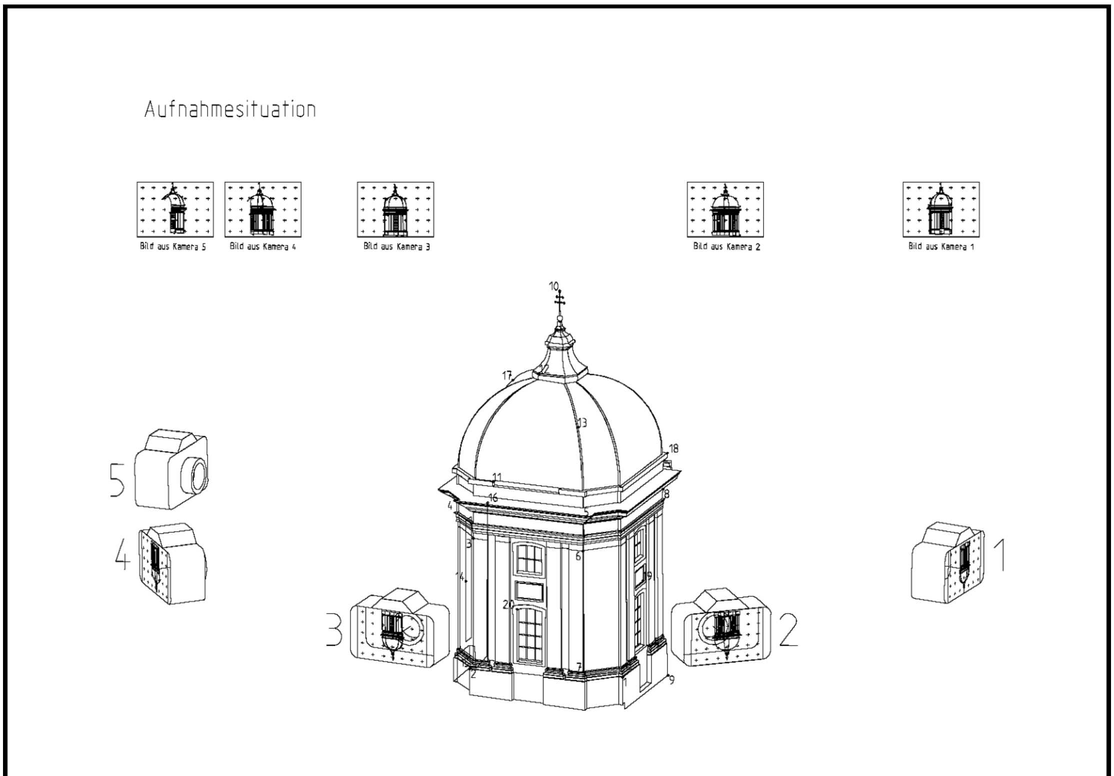
Flags for the observation type:

11	spatial distance
12	X coordinate
13	Y coordinate
14	Z coordinate
15	X difference
16	Y difference
17	Z difference
18	camera constant c
19	principal point coordinate x_h
20	principal point coordinate y_h
21	radial-symmetrical distortion A_1
22	radial-symmetrical distortion A_2
23	radial-symmetrical distortion A_3
24	tangential-asymmetric distortion B_1
25	tangential-asymmetric distortion B_2
26	camera station X_0
27	camera station Y_0
28	camera station Z_0
29	camera rotation ω
30	camera rotation φ
31	camera rotation κ
32	distance of 2 camera stations
33	difference in X_0
34	difference in Y_0
35	difference in Z_0
36	difference in ω
37	difference in φ
38	difference in κ

14. Basics of Image Orientation

For photogrammetric orientation the module MBUN is available. MBUN is a program for orientation of image mosaics, based on bundle block adjustment. Herein, the photographing situation is mathematical reconstructed in such a way that all corresponding image rays are fitted in the best possible way on each other. At the same time the calibration parameters of one or several cameras can be calculated with MBUN. MBUN is primarily conceived for close-range applications and that is why it provides the possibility to additionally introduce non-photogrammetric observations – like distances or coordinates – into the orientation calculation. For special applications the orientation can be calculated as a so-called free network. Herein, the datum of the image mosaic can be fixed by a specific selection of object points. MBUN forms a complete inverse of the normal equations and disposes of suitable tools for statistical evaluation of the data. Among these are the search for blundered observations, the derivation of accuracy measures for the estimated parameters and the a posteriori estimation of variance factors. The number of images and points to be processed by MBUN is not limited, it depends only on the available storage.

A special feature of MBUN is the possibility to use line data, more exactly, straight lines, for image orientation. The following statements refer exclusively to the description of the classical approach which bases on the coordinates of image and object points. The extensions and peculiarities in context with line photogrammetry are described in chapter 14.10.



General case of photogrammetric evaluation: the three-dimensional object to be surveyed is photographed from several stations. Herewith, it is important that the photos are taken from different locations while, nevertheless, neighboring images show a sufficient lap. Every object element has to be shown in at least two images, as far as possible.

14.1 Conditions for Image Orientation

The image orientation usually assumes that in the photos the image coordinates of the control and tie points have been measured. Within the following considerations it is exclusively assumed that the image coordinates refer to fiducials or réseau, that means the transformation of the coordinates from the underlying measuring system into the image coordinate system has already been done. Control point coordinates can, but need not be available. Moreover, besides image coordinates, in particular cases also additional observations could have been made. By additional – or in general non-photogrammetric – observations all observations are meant which establish a geometrical relation for or between individual unknowns. The non-photogrammetric observation types which can be processed are specified more detailed in a later section.

14.2 Mathematical Model of the Bundle Adjustment

The mathematical model of the bundle adjustment is non-linear what requires the supply of approximate values for the unknowns. The relation between the observed image coordinates (x, y) and the unknown quantities are established by the well-known collinearity equations:

$$x = x_h - c_k \frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} + dx$$

$$y = y_h - c_k \frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} + dy$$

Unknowns are in this context primarily:

- the external orientation data of every single photo, thus the three-dimensional coordinates of the projection center (X_0, Y_0, Z_0) and three rotation angles (ω, φ and κ in the form of the rotation matrix components r_{ij}) around which the camera-related image system is rotated in relation to the defined object coordinate system

- the three-dimensional coordinates (X, Y, Z) of the object points which guarantee among other as tie points the establishment of the image mosaic

- and, in case, the calibration parameters of the image recording system, that is the interior orientation with camera constant (c), image principal point coordinates (x_h, y_h) and distortion parameters (in dx, dy).

Because of the non-linearity of the observation equations the first aim of the image orientation must be to determine approximate values for all unknowns, provided that they are not already known otherwise. Only the parameters of interior orientation, provided that they have to be determined simultaneously in the bundle adjustment, can generally be directly given approximately. As camera constant the focal length of the camera lens is used and for all other parameters it will do to set them to zero. All other approximate values are usually calculated through a certain processing sequence by the combination of basic orientation tasks like relative and absolute orientation as well as resection, because in close-range applications the manual setting of approximate values often is a too big effort.

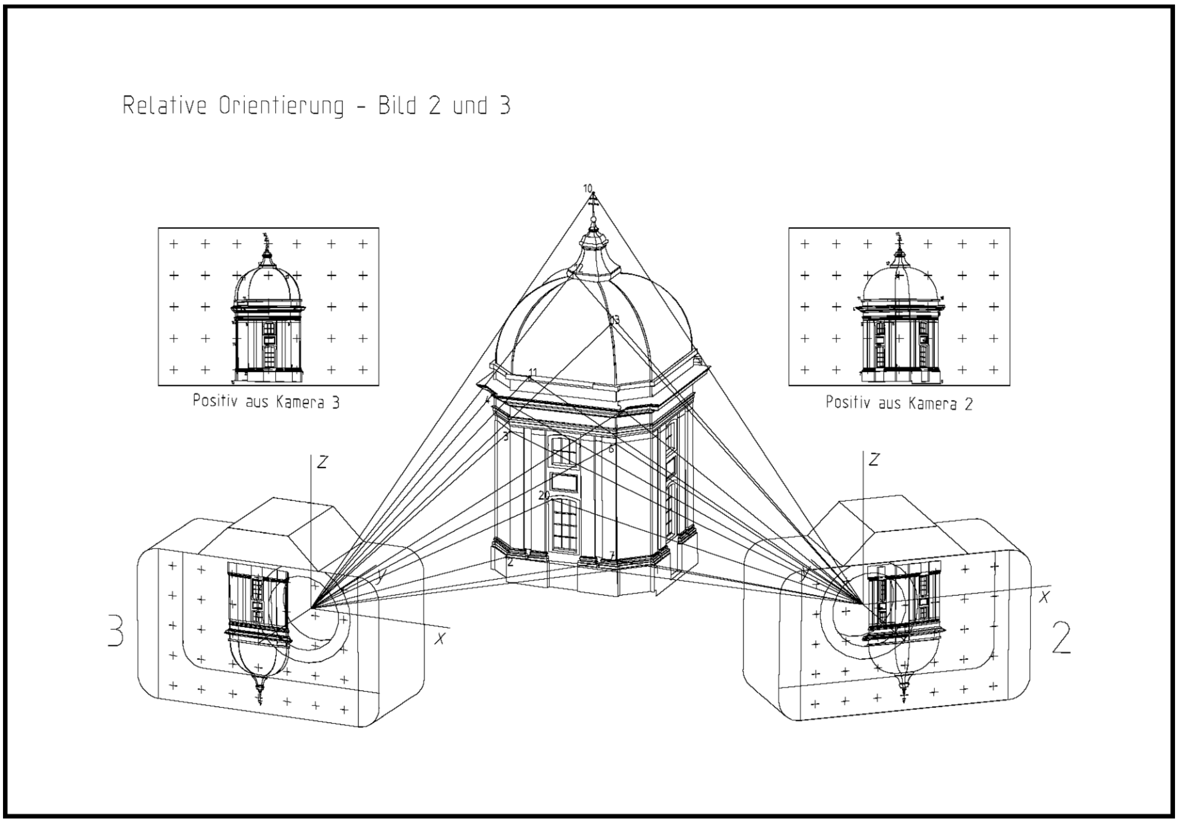
The basic process of the actual image orientation consists of a sequence of several processing steps which are shortly explained in the following.

14.3 Relative Orientation

In the first step relative orientations are calculated. For this each two suitable photos are to be combined, in which the image systems of both photos are computationally put into relation to each other so that all corresponding image rays cut each other under least residual gaps. The minimum number of corresponding points or image rays per image pair is five, as is known, while for a well-determined relative orientation there should generally be taken care to use at least 7 to 8 homologous points. The principle of redundancy in parameter estimation applies, moreover, to all other calculation steps in the same way, because only so, gross errors can be fairly reliably uncovered in the data. As result of the relative orientation we obtain in so-called models three-dimensional coordinates of the cutting-points of homologous image rays. Therefore, to each image pair belongs a different model with corresponding model coordinates of the spatial model points. Among the individual model coordinate systems no relation exists yet at first.

Apart from the necessary minimum number of common points, at the selection of the image pairs the following criteria should be noticed above all:

- The model points result as ray intersections. Through this arises the demand that the camera stations do not lie too tightly together, so that the intersections are not too glancing. Therefore, the base between the camera stations should have a certain minimum size depending on the average photographing distance. All photos which have been taken from nearly the same location therefore cannot be potential image pairs for relative orientation. In MBUN it is referred to unfavorable constellations, see more about this below.
- hose image combinations are to be preferred which have on the one hand as many as possible common points as possible, and on the other hand a favorable distribution of the points over the whole image. Through this the obtainable accuracy of the relative orientation increases and blundered observations can be determined with more significance.



Relative orientation: each two images establish a so-called *model*. Using common image points, the relative position to each other can be reconstructed. As result of the relative orientation one obtains per image pair three-dimensional model coordinates in a local coordinate system (model system). The relative orientation is first of altogether three steps to determine approximate values, there follow absolute orientation and spatial resection yet.

- The relative orientation can be finished generally if for all object points which should be used in the further process of image orientation, model coordinates have been calculated at least once. This applies anyway to the control points, because on them depends the datum definition, thus the bearing of the object within the object coordinate system. Also should be taken care to determine all tie points as complete as possible, so that the possibly later following junction of models in absolute orientation succeeds. Since for this a sufficient number of common points in the models is required.

The order in which the models are formed possibly has an influence on the accuracy and – in extreme cases even – on the result of the image orientation. That is why it is advisable to choose the order following the mentioned criteria which are a measure of quality of the models.

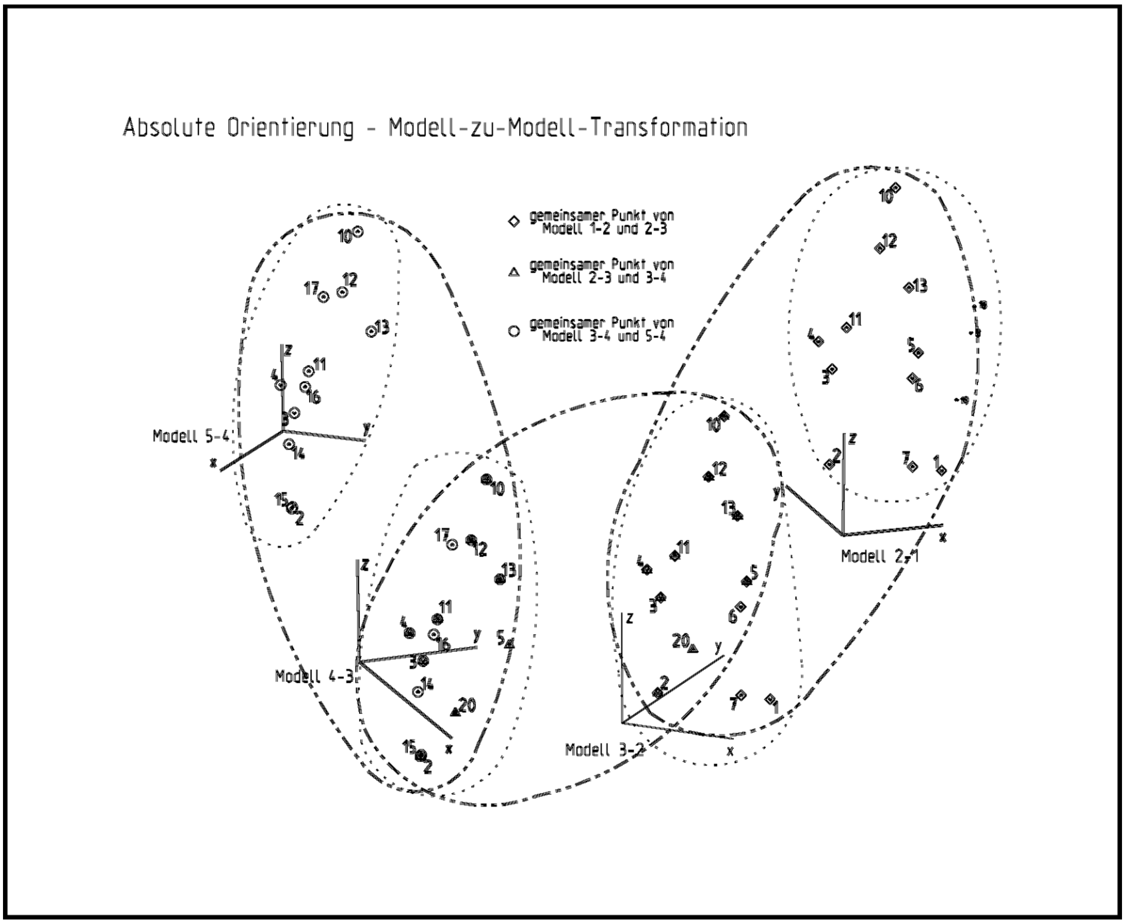
	Procedure	**program part**	**result**	**file**
1	establish project	*Project*	settings for program control	
2	Preparation - calculate control points - identify camera lens	*Edit data*	- control points coordinates - approx. Camera data	OPK KAM
3	measure fiducials		transformation of fiducials	KAM
4	measure image points - control points - new points		1. image coordinates of control points and new points 2. relation camera <> image	BPK EOR
5	relative orientation	*Relative orientation*	model coordinates of control points and new points	MOD
6	absolute orientation a) model to model b) into object system	*Absolute Orientation*	 a) model coordinates in the reference model's system b) approximate values of new points	 MDV MOD OPK
7	single photo orientation	*Single photo orientation*	approximate values of orientation parameters	EOR
8	define non-photogrammetric observations (optional)	*Edit data*	- additional observations - constraints	NPB
9	bundle adjustment	*Bundle adjustment*	adjusted values for - orientation parameters - camera parameters (calibration) - coordinates of new points	OUT
10	accept results	*Results*	for the photogrammetric analysis - image orientations - camera parameters	 EOR KAM

The most essential steps of image orientation and its partial results. The column *'program part'* corresponds to the "main menu" of MBUN. In column *'file'* the file name extensions of the files are given into which the results of the respective step are written.

14.4 Absolute Orientation

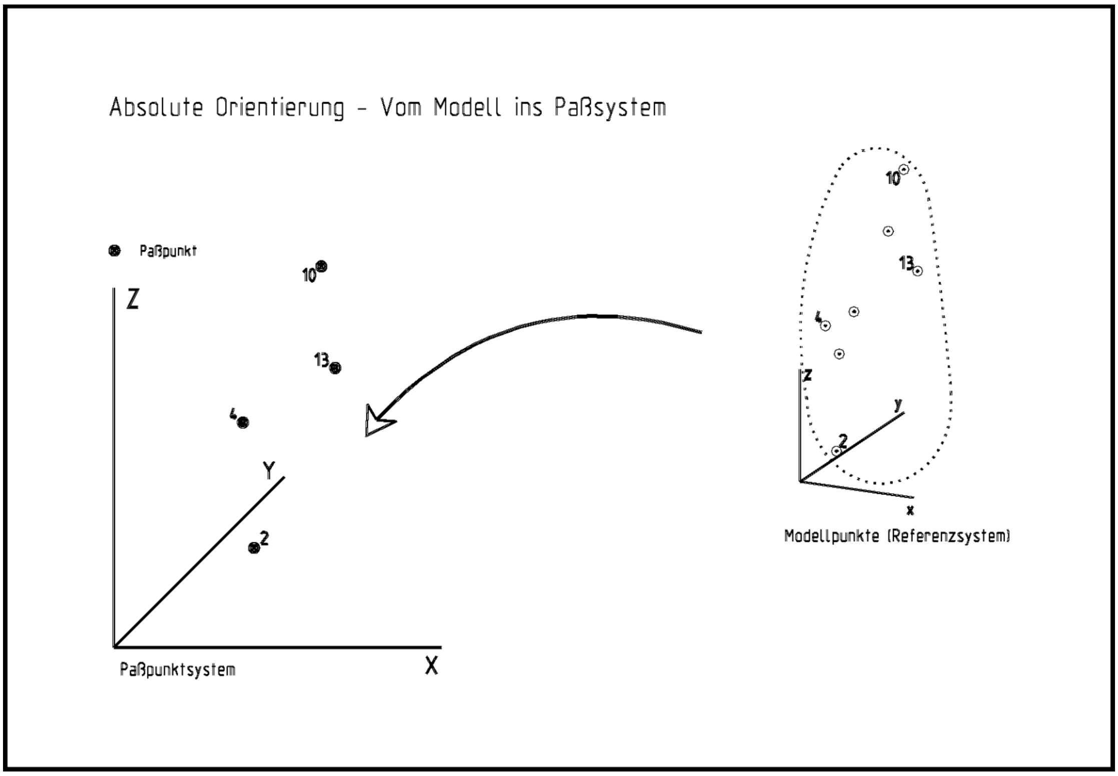
The procedure absolute orientation is used in two respects.

1. On the one hand, above all with long-stretched objects it is necessary to transform the models generated in relative orientation, together with their model points, to a common coordinate system. As a suitable reference system generally one of the models is chosen. This is necessary primarily if there are models which are established exclusively by tie points, because then the junction to other models has to be sought for by concatenated transformations, which models do also have control points, besides tie points. In this context the entire feasibility of the image orientation depends even on a skillful choice of the order. The reference to the control point system common to all points is important to the calculation of the external orientation parameters in the next processing step. If no control point coordinates are given, the transformation of all models to a common reference system is even a necessary condition to proceed with the orientation calculation.



Absolute orientation – from model to model: the purpose of the model-to-model transformation is the unification of the model points from the relative orientation into a common coordinate system. Generally one of the models is selected as reference model, to which all others are transformed using at least 3 common points in each case.

2. On other hand in the absolute orientation the models – or the reference model – are transformed to the control system. This step assumes the existence of object point coordinates which have been otherwise determined, for instance, by geodetic measuring methods. In some cases the models can also be transformed directly to the control point system, so that the concatenation operation described before need not be done. This is possible namely if in each model exists a sufficient number of control points.



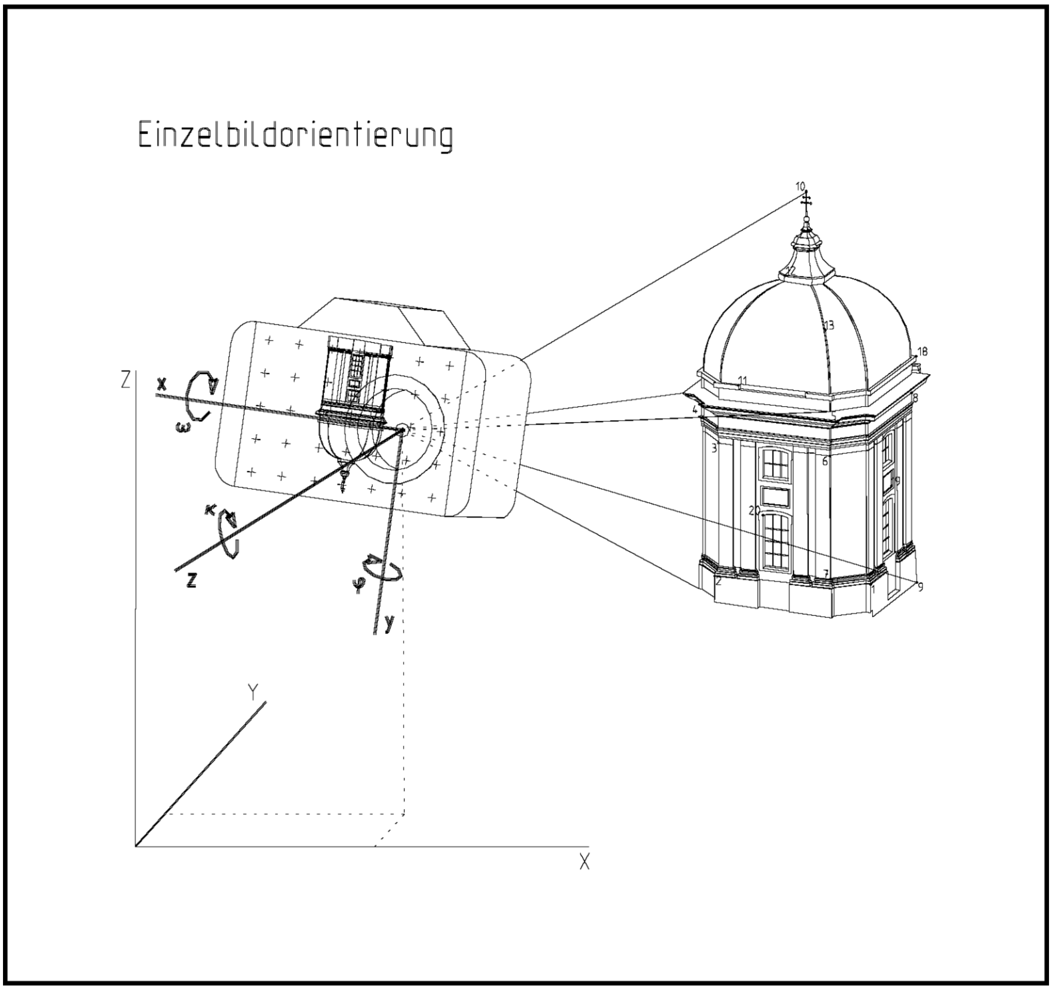
Absolute orientation - from model to the control system: finally, the model points are transferred into the object coordinate system. Result of the successful absolute orientation are the approximate coordinates of the new object points.

The absolute orientation is based on the principle of a spatial Helmert (overdetermined similarity) transformation. Therefore, as a minimum condition for the transformation between two models three common points are required which must not all lie on - or near – one straight line. Here, too, applies the principle that for accuracy and reliability of the calculation results substantially more identical points should be available. Accuracy and reliability profit from a high number of most equally distributed points, and if the order of the transformations is made dependent on the quality of the models. Object points for which model coordinates have been determined in models with relatively bad geometrical constellation should only last be transformed to the reference system.

Result of the absolute orientation are the approximate values of the three-dimensional tie point coordinates in a common object coordinate system. The object coordinate system is, if control points do exist, the given control system, or, if control points are missing, a suitably chosen reference system. This reference system is attached in the latter case mostly to suitable fixed points of the object, for that the coordinate system is, e.g., levelled, and the later processing is facilitated. MBUN has appropriate aids for the realization of these tasks.

14.5 Single Photo Orientation (Spatial Resection)

Now after the absolute orientation the approximate coordinates of the new object points as well as, of course, the control points are available for the determination of the external orientation parameters. The computational procedure to determine approximately the projection center and camera rotations of each photo is based on photogrammetric resection. Because all images are processed independently of each other, in principle no certain order needs to be kept.



Frame orientation: the frame orientation (spatial resection) is the last of three steps of the determination of approximate values. Using the object points (control points and approximated new points) for each image the camera location and the camera rotations are determined. Thus approximate values for the data of the external orientation are available then.

The theoretical minimum number of points for spatial resection is three, however, the external orientation parameters are determined only with insufficient accuracy and reliability, if not essentially more (minimum 6 to 8) object points are available. The resection is of all processing steps the most problematic one because here quite possible singularities and ambiguities can arise by which the calculation result is wrong or not determinable at all. In MBUN several algorithms have been built-in which should help to overcome these difficulties, however, independently from that, the most attention is to be paid to check the results of this processing step.

14.6 Input of further Observations

By successful ending of the last processing step now all approximate values of the unknown points and external orientation parameter are known. The data model of the bundle adjustment can be complemented by additional observations which can take straight influence on the orientation result. For this, additional observations are used in different manners:

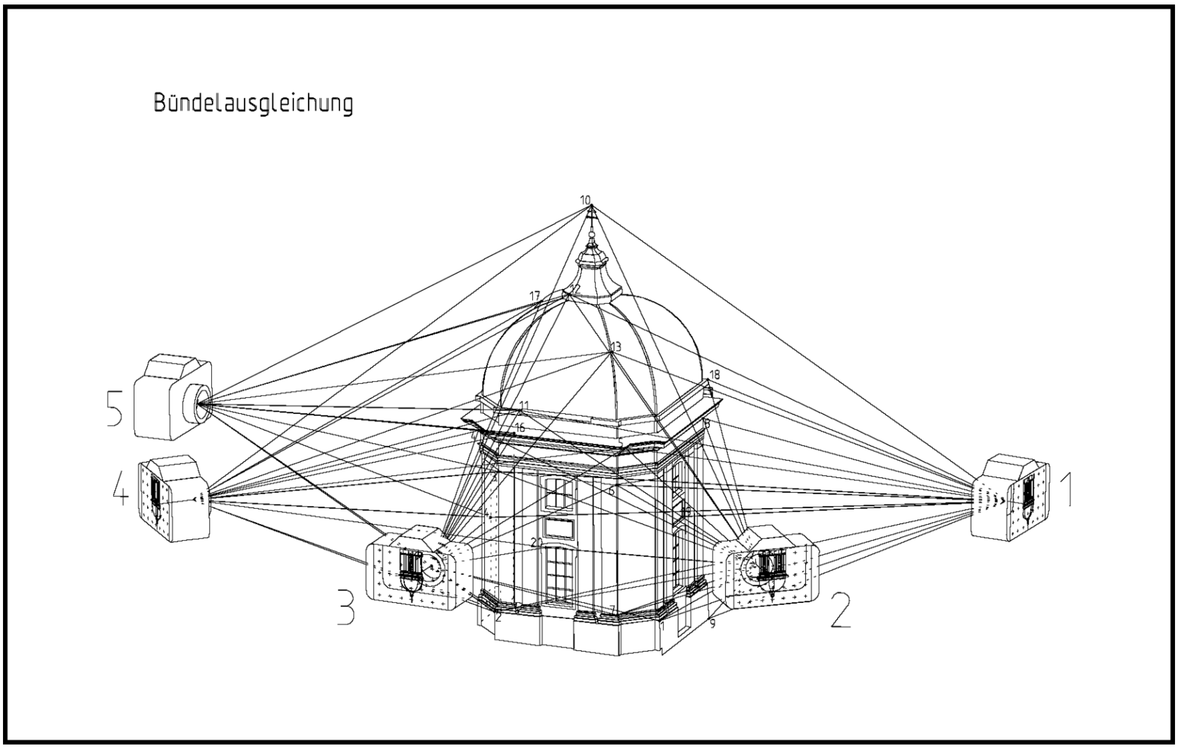
- The most obvious way is to introduce geodetic observations. For example, this may be spatial distances between two points, or coordinate differences were observed. At this, the additional observations are treated in the same way as the image coordinates what is expressed by giving a realistic measuring accuracy for the respective observations.

- The other possibility uses the additional observations to formulate condition equations. Such equations are put up generally as conditions among two or also for single unknowns. In MBUN restrictions are realized not by a functional set-up in the adjustment model, but by corresponding additional observations. With appropriately high weights for these observations the conditions are kept numerically. By input of very low observation accuracies there result inversely very high weights, so that, for instance, a given coordinate difference is preserved in the orientation calculation with accordingly high accuracy.
- Besides an extremely high weighting which causes the transition of an additional observation to a restriction many intermediate stages are conceivable. The "mobility" of the unknowns can be controlled straight by variation of the observation weights between both extremes. Thus, for example, uncertain control points can be declared primarily as new points which are indeed estimated in the bundle adjustment as unknowns, but which are only partially movable because of corresponding additional observations with appropriate weights.

The different possibilities and particularities of the introduction of additional observations in MBUN are reported in more detail in a later chapter about operating the software.

14.7 Bundle Adjustment

The bundle adjustment is the essential core of the whole orientation procedure because there after all the most optimum results for the orientation data and the new point coordinates are calculated. The mathematical relation between the observations and the unknown quantities is established by the collinearity equations. The same functional is used in photogrammetric resection, which is why a bundle block adjustment can be also regarded as a concatenation of resections.



Bundle adjustment: the photos are oriented after all in a so-called *bundle adjustment*. All ray bundles are hereby fitted on each other by distributing the measuring inaccuracies the best possible. Successful bundle adjustment gives then the prerequisites for the photogrammetric survey of the object.

A special variant is the free network adjustment which is characterized by the absence of control points. By that the datum of the object points is not fixed and the adjustment system becomes singular. Now the specific to the orientation in free network is the manner in which the datum defect is removed: the available normal equation system is complemented with well-chosen additional equations, which remove the singularity of the linear equation system. These additional equations work like conditions which leave unchanged the center of gravity of the points included into the datum definition, and which determine the coordinates of the datum points such that the sum of the squared distances to the approximate values is minimized. This is in this context also called a parameter transformation of the datum points to the approximate coordinates by which the orientation result depends after all also on the approximate values. This fact is to be considered with the orientation in free network. However, beyond it, the free network adjustment is preferably also used to assess the internal measuring accuracy of the observation data. Because the adjustment result are in this case not influenced by the tie points, the corrections of the observations are influenced only by the measured data and thus an unbiased representation of the intrinsic observation accuracy is obtained. That is why the method of free network is preferably also used for a posteriori assessment of the measuring accuracy, that is the actual measuring accuracy is determined in the adjustment by estimation of variance components, where the components refer to groups of observations of same type. In photogrammetry provides, e.g. to treat x coordinates and y coordinates of the image points as a respective observation group. The estimated variance components are the factors by which the originally set variances (accuracies) of an observation group must be multiplied, so that the adjustment is done with the "true" accuracy ratios. The essential aim of the bundle adjustment – as above all the unknown camera orientations and new point coordinates as well as their respective accuracy – depends namely not only on the absolute value of the introduced observation accuracy of the image coordinates, but rather on the ratio of the standard deviations or variances of the individual observation groups. In course of a variance component estimation, for which the adjustment is to be done repeatedly (3 to 4 times), the actual accuracy ratios between the observation groups can be determined. This should be done in a free network, for that the result is not corrupted by inaccurate fitting data.

At the end of the bundle adjustment the observation data are examined concerning gross errors. According to the theory of the statistical outlier test, strictly speaking, thereby only one single outlier can be uncovered, because with the basing adjustment principle blurring effects go along. On account of this fact always only one faulty observation per flow should be removed, and then the new adjustment result should first be awaited. It is therefore advisable, in presence of gross errors, to execute the image orientation in several flows, until all gross errors have been removed in turn.

14.8 Special Cases of Image Orientation

Up to this the course of the orientation procedure has been explained as it is applied in practice in most cases. In special cases there can be deviations from the descriped schedule, mostly in the following cases:

- In the absolute orientation the single models from the relative orientation first were transformed to a selected reference model. This step need not be done, if a sufficient number of control points are available, so that each model can be transferred directly to the control point system. This presupposes that each model is equipped with at least 3 control points.

- If the number of control points is very large and at the same moment only very few images are in a project, then the single photo orientation (resection) can be also done directly, using these fixed points. The first two steps – relative and absolute orientation – are therefore not done. Indeed, only the approximate values of the external camera orientations can be determined then. If, in addition, new points should be used whose (approximated) coordinates are not known yet, the complete orientation procedure has to be done as described.

14.9 Photogrammetric Survey

The tool of the photogrammetric image orientation pursues, firstly, the goal to calculate as accurately as possible the elements of the image orientations – that are the coordinates of the projection centers and the rotations of the image system against the object system at the time of exposure. If these are known once, the actual processing and measurement can begin. Then each accessible object point is determined in three dimensions by intersection of two or more image rays, where the intersection geometry is defined by the orientation data.

Nevertheless, for very precise measurements the bundle adjustment is also usable, because with it, best possible results for individual, discrete points are attainable. For this, the object points are fitted suitably with signal marks, whose images are localizable in the photos with high precision (perhaps using image processing methods). If the object points exist at the same moment in several images, the three-dimensional coordinates can be determined through the image orientation with high redundancy and thus with great reliability and accuracy.

14.10 Straight line Based Image Orientation

Besides the usual coordinates of image and object points also lines can be used for image orientation.At this, the basic mathematical relations of photogrammetry, as for example collinearity equations, can be applied throughout analogously to the observation type "straight line". Now, however, instead of image rays there are "image ray planes" which relate through the common projection center, the image lines to the object lines. In the individual processing steps of the image orientation, point coordinates and line parameters are used totally congruently. In this chapter some explanations are given which are especially important with the usage of lines. (If here, for short, the term 'line' is used, it is always meant a stright line.)

14.10.1 Line Parametrization

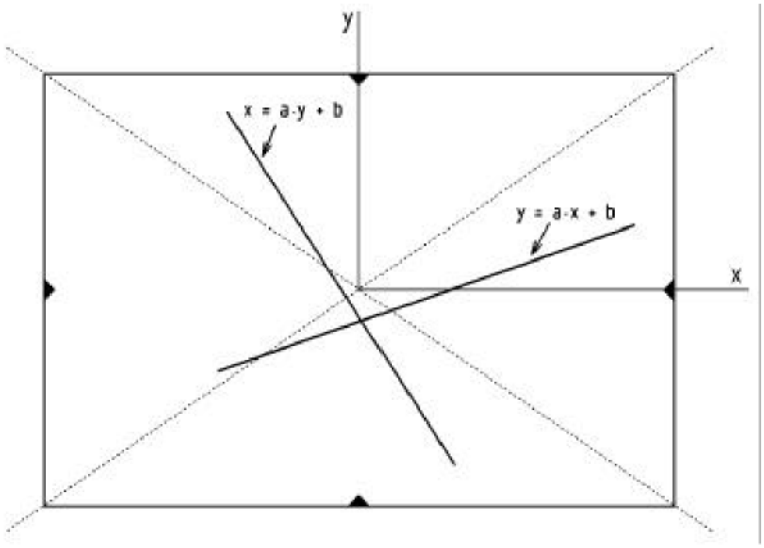
Straight lines in two- and three-dimensional coordinate space can be described mathematically on principle in different ways. For the work with the program two variants of line parametrization are of importance. To the outside – thus for the user apparent – lines are represented in general by their end-points. Therefore, in the suitable files the two- or three-dimensional coordinates of these line end-points are to be found. The representation by end-points needs no further explanation and has the advantage that position and direction of the lines are to be interpreted relatively simply and directly. Nevertheless, the disadvantage of end-point coordinates is the fact that more parameters are used than are actually necessary. Since straight image lines are uniquely defined by 2 and straight object lines by 4 parameters. However, for implementation of the line calculation in image orientation is a redundancy-free representation of advantage. Therefore, internally a second, special parametrization is chosen in the program, for the image lines as well as for the object lines.

Image Lines

The image lines are shown in the two-dimensional image coordinate system in the classical normal form, thus with the gradient ratio a and the axis intercept b. The gradient a has dimension one, while b is counted in mm. To avoid singularities as well as numerical inaccuracies, two so-called representation systems s_1 and s_2 are distinguished. In which representation system a line is described, depends on its position in the coordinate system (see also following picture).

s_1: $y = a_x \cdot x + b_x$ s_2: $x = a_y \cdot y + b_y$

For the user the distinction of representation systems has only lesser importance, because the practical handling is not essentially influenced from this.



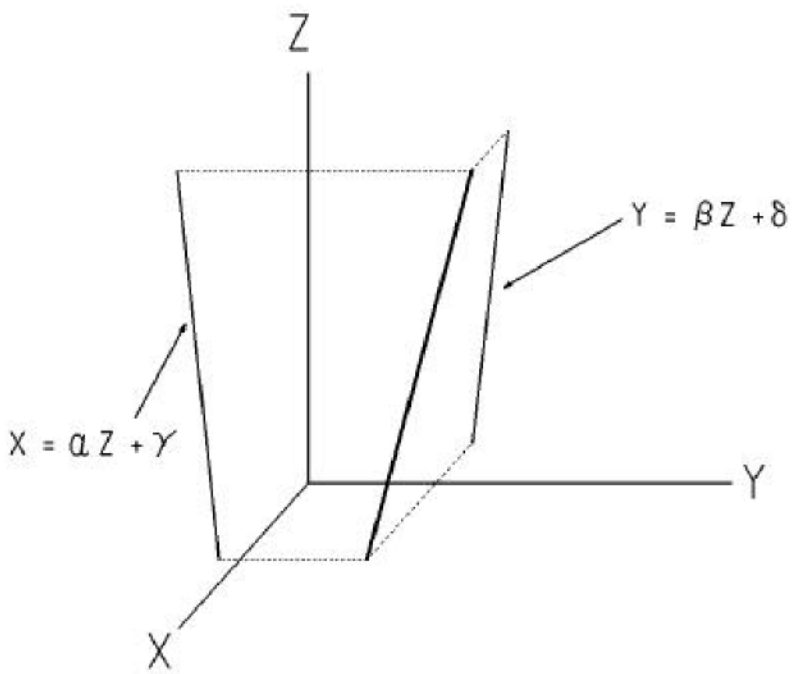
Parametrisierung der Bildlinien

Object Lines

The redundancy-free parametrization of the object lines in the three-dimensional coordinate system is done by so-called 2-view projection. Thereby, the line is projected onto two coordinate planes, and in these planes then defined – like image lines – by gradient and axis intercept parameter, which are called here now α, β, γ and δ.

S_1:	$Y = \alpha_x \cdot X + \gamma_x$	and	$Z = \beta_x \cdot X + \delta_x$
S_2:	$X = \alpha_y \cdot Y + \gamma_y$	and	$Z = \beta_y \cdot Y + \delta_y$
S_3:	$X = \alpha_z \cdot Z + \gamma_z$	and	$Y = \beta_z \cdot Z + \delta_z$

To shun singularities here, too, representation systems are distinguished, now, however, three ones. In which system a line falls, depends on its proximity to the axes of coordinates.



Parametrization of object lines; here exemplarily made clear using a line in the representation system S_3.

It applies also to the object lines that the internal parameter representation is for the user only of lesser importance, because to the outside always the line end-points are given. Nevertheless, these relations are valuable informations for the understanding and handling of the straight line based orientation, in particular, for instance, if it is about the definition of measurement accuracies.

14.10.2 Use, Advantages and Disadvantages of Straight line Based Image Orientation

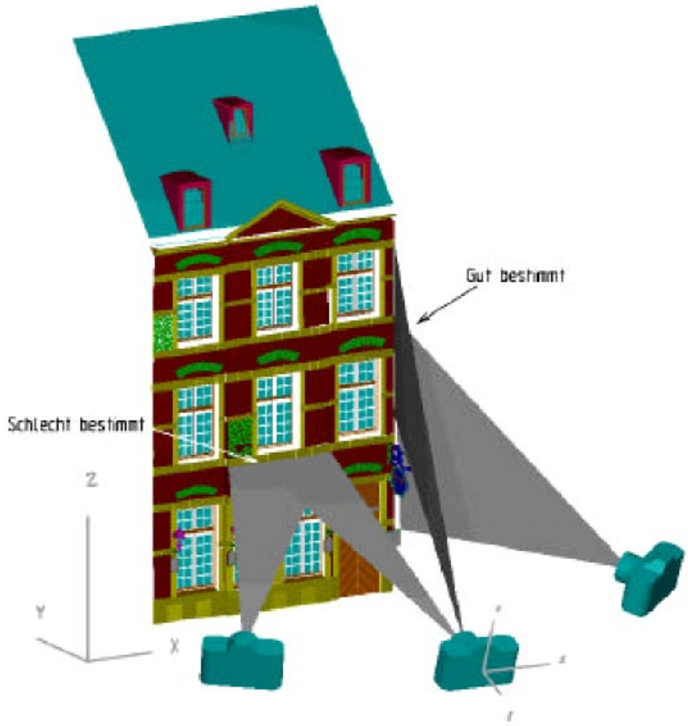
The use of straight lines in the image orientation should be regarded generally as a supplement measure. Indeed an orientation is possible on the basis of exclusively lines mathematically and practicable in principle, one should do this, however, only in exceptional cases. Since the accuracy can never be as good as in the point-based orientation what already arises from the following, simple reflection: finally the lines deliver only vertically to their run direction fixing information, in run direction the position is basically uncertain. This is different with point information, because in all coordinate directions the identical definition behavior exists. Therefore, in practice one should start both observation types combines or the line data only in addition.

Lines can be helpful always with the orientation when it is very difficult on account of the object structure or barely possible to measure enough homo-box points for the image linking. A conceivable application example is the photogrammetric measurement in the investment construction. Here are often missing well defined points, whereas a sufficient number of straight object edges can very well be found. Before one falls back on the preceding signalling with artificial points, the orientation can be led if necessary also by the complementary adding of lines to the success.

As an essential advantage of the lines the fact is to be regarded that one can renounce the identification of homologous points. Indeed the lines are defined in the images also by points, nevertheless, i.e. their measured end-points, these points need not be homologous in the images. Into the single orientation steps the line is introduced as information only in the form of their position and orientation as information.

Nevertheless, with the use of lines in the image orientation there are also peculiarities or disadvantages which there are not in this form with the classical point data. The user should keep an eye on the following aspects:

The basic principle of the photogrammetric object measurement is the intersection of oriented image rays. In case of from lines oriented planes step to the place of the rays (straight lines) then whose cut the straight line define in the space. Now is to be followed in this context that these "image ray planes" decisive for line not always lie geometrically favorably to each other that still singularities can appear. The circumstances can be very simply made clear using the standard task of the close-range photogrammetry: the measurement of a building front. If then – as is often the case – all photos are taken from the surface of the earth, primarily only the vertical building edges are reliably determined. With the horizontal object lines are, however, strongly dragging slice which can be uncertain in the extreme case even mathematically. In these cases it is spoken in this program also of " weak lines “. It depends on the adjustment of the object line in comparison to base between the photos. In the particular case should be shown consideration by the planning and realization of the photos for these circumstances.



Zur Problematik von „Schwachen Linien"

On account of the special parametrization of the lines the lens distortion can be brought only incompletely in arrangement. The distortion is a local function of the image coordinates which a just object edge illustrates to a more or less very stooped curve. How strong this degeneration is, depends among other things also on the adjustment of the line in the image. A mathematical modeling is nearly excluded before the background of the line parametrization described above, so that a certain amount of loss in accuracy must be accepted. The distortion is taken into consideration with the orientation to a certain extent averaged. Authoritative is moreover the center or center of gravity of the line in the image from which, at last, the distortion amount is derived, like with point data.

On account of these connections it plays for the quality of the orientation also a role how long the lines measured in the images are; this all the more, the stronger becomes apparent the distortion in the photos. From the point of view of the reliability and determination certainty from the lines should be rather long as far as possible. Before the background of the described circumstances in context with the distortion it is more favorable however, if the lines are short. In the practical application a compromise must be found here. As a rule of thumb can be held on that the length of the lines should amount at least 1/20-1/10 and maximum 1/4 (better 1/8) of the shortest image side.

In the end, one has to make it in comparison with image points with the line parameters with totally other observation types which are still different together themselves. The gradient ratio a has dimension one and the axis intercept b is measured like usual x and y coordinates in mm. Through this an adequate definition of the a priori-measurement accuracy is incomparably more difficult than with image coordinates. In this context must be pointed out to the fact that a and b, actually, derived dimensions are whose standard deviations must be determined by error reproduction. Through this every measured line is fitted out with individual a-priori accuracies. A such differentiation it is renounced here, i.e. all lines come with the same standard deviation into the adjustments. To determine objectively the accuracy ratio of the line parameters to the image point coordinates (variance components), should be gone back in the particular case to the estimation of variance components within the bundle adjustment.

Subject Index

Restriction of warranty

No warranty is accepted for the correctness of the contents of this manual. We always appreciate references to incorrectness not known to us so far.

Contact address

With questions and lacks of clarity the provided manuals should be consulted first.

If the difficulties cannot be removed, we ask you then to write to the following address. Telephone inquiries should be made only in urgent cases.

With all inquiries keep at hand the day of the license acquisition and the license number.

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