A software system for automated off-line digital close range photogrammetric image measurement, orientation/ triangulation and sensor calibration

Users Manual

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Summary of *Australis* Features

The *Australis* photogrammetric software package is designed to perform highly automated off-line measurements from monoscopic/convergent digital image networks, either using digital cameras or scanned film imagery. It is equally useful for high-precision metrology applications using 'metric' digital cameras (or scanned imagery) or low- to moderate-accuracy measurement employing off-the-shelf, amateur still video CCD cameras. Through the integrated image measurement, preliminary orientation and bundle adjustment functionality, one can quickly and easily obtain three-dimensional object point coordinates and sensor calibration data from multi-sensor, muti-image networks of an effectively unlimited number of object points. Moreover, depending on the provision of an exterior orientation (EO) device and high contrast targets, the photogrammetric orientation/ triangulation and calibration processes can be carried out fully automatically, in semi-automatic mode, or even with manual image point measurement and a more sequential processing flow. Australis is thus ideal for the teaching of photogrammetric principles and practices and it a valuable tool in both research and for practical measurement applications.

Salient features:

- **Fully automated orientation/triangulation and sensor calibration when using high-contrast targets, and an EO device (seen by all images)**

  This 'one-button' operation includes AutoScanning to measure all candidate targets, centroiding of all valid targets, identification and measurement of the EO device, exterior orientation, image point correspondence determination and final self-calibrating bundle adjustment.

- **Also features step-by-step processing, manual and automatic, for use in the teaching of close-range photogrammetric principles**
- **Able to handle multiple sensors and networks of hundreds of images and thousands of object points**
- **Can accommodate virtually any digital camera, from popular 'off-the-shelf' models to large-array professional CCD cameras**
- **Can measure and photogrammetrically process scanned film images, and incorporates interior orientation capability (fiducial/reseau transformations)**
- **Self-calibrating bundle adjustment incorporates flexible choice of the sensor calibration model and has graphics display of distortion profiles**

- **Incorporates different options for initial network exterior orientation, including Relative Orientation (RO) and Resection/Intersection, with RO requiring no initial object point coordinate information**

- **Bundle adjustment uses either a free-network solution (via inner constraints) or one with a surveyed control point configuration.**

- **Allows interactive assignment of object space XYZ coordinate axes via so-called 3-2-1 method which sets coordinate system origin and axial orientation**

- **Integrates a 3D coordinate transformation function (very useful in conjunction with free-network solutions)**

- **Supports export of XYZ object point coordinates in DXF or ASCII format**

- **Allows imposition of scale constraints in either post adjustment scaling or as distance observations within the bundle estimation process**

- **Supplementary object space analysis functions: distances and best fit line, plane, sphere, circle, cylinder**

- **Convenient, project-based user interface**

  An *Australis* project file stores all cameras, images, scalebars, and measurements. The Camera and Scalebar database contains all available calibrated cameras and scalebars.

- **Centroid and manual target measurement**

  Automated image scanning and centroid measurement of high-contrast targets (typically retro-reflective) or manual measurement of natural features. Supports associated automatic exterior orientation via either 'known points' or an EO device and facilitates 'resection driveback'.

- **Graphics View**

  3D graphics view for visualisation of point cloud, cameras, and scalebars. Includes point-to-point distance and best-fit circle, line, plane, and sphere functionality, as well as 2D graphics of various image-related features (residuals, labelling, etc.)

Upgrades to Version 6.0 incorporated into Version 6.01:

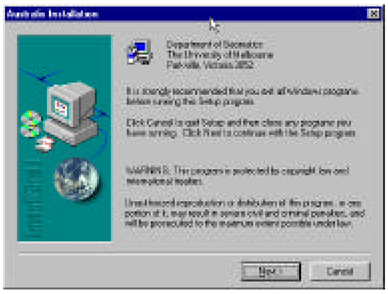
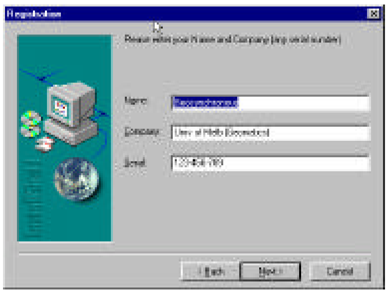
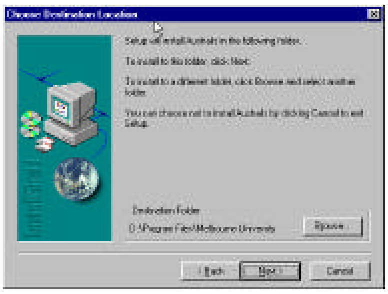
- The X-Y-Z axes for any 3D object point file can be set interactively via a so-called 3-2-1 process (Section 9.2)
- Imaging rays can be shown in the 3D graphic view, individually or collectively (Section 7.2)
- 3D data files can now be output in DXF format (Section 3.2.6)
- Camera stations can be added as object points to any 3D data file (Section 7.1.7)

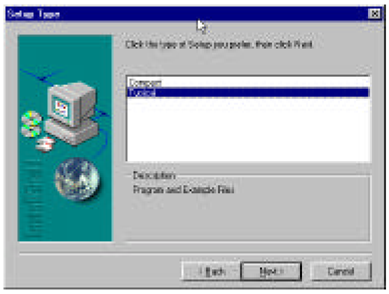
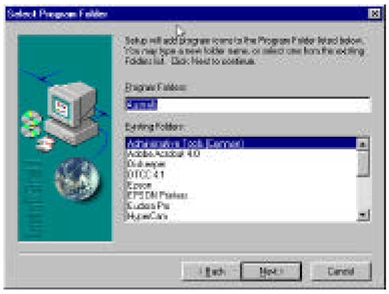
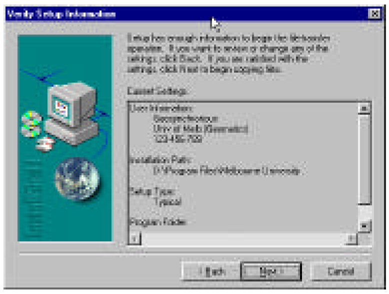
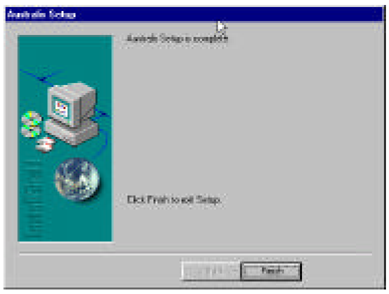
1. Overview

1.1 Introduction

This document describes the functionality of the *Australis* digital photogrammetric software package. *Australis* is designed to perform automatic and semi-automatic photogrammetric measurements from digital imagery. Using the program functionality one can quickly and easily obtain three-dimensional object point coordinates from two-dimensional image observations.

1.2 Installing Australis

To begin the installation, run *setup.exe* from the *Australis* cd-rom. After the setup preparation is complete the *Australis Installation* screen appears. Choosing the **Next** button brings up the *Registration* screen.	
Enter your name and company name. Serial numbers are not utilised in the installation procedure at this time. However, the serial number box must be filled in. A dummy number (123-456-789) is entered automatically. Click the **Next** button to proceed to the *Destination Location* dialog.	
By default, the destination folder is $:\Program Files\Australis, where $ represents the drive letter where Windows 95/98/2000, NT or XP is installed. It is recommended that this folder be utilised. If it is necessary to change it, use the **Browse** button. Choose **Next** to go to the Setup Type dialog.	

Here, you must choose between the *Compact* and *Typical* setup types. The *Compact* setup installs necessary program files only. The *Typical* setup additionally installs tutorial files and this is the usual option selected. Select the setup you prefer and choose **Next** to bring up the *Select Program Folder* dialog.	
Here you can change the folder to which program icons are added. It is recommended to use the default folder, *Australis*. Choosing **Next** opens the *Verify Setup Information* dialog.	
Current installation settings are displayed here. To review or change any settings, click the **Back** button. Clicking the **Next** button here will start the file copy procedure. Upon completion, the *Finish* dialog appears.	
Choose **Finish** to exit the setup program. **Note:** When *Australis* is installed, the supplied *Australis.ini* file will not overwrite an existing *Australis.ini*. Thus, if the newest file is preferred, simply rename the current file for safe keeping.	

1.3 Uninstalling Australis

From the **Start** menu, choose **Settings** and **Control Panel**. From the **Control Panel**, choose **Add/Remove Programs**. Highlight *Australis* in the list of available programs and click **Add/Remove**. All program components will then be removed.

1.4 Starting the Program

To run *Australis*, click the Start menu and choose *Programs* and *Australis,* or double-click on the *Australis* desktop icon. To set shortcut icon, right click on the *Australis* executable icon in the $:*Program Files\Australis* directory in Windows Explorer (the $ represents the drive). Choose Create Shortcut from the popup menu and drag the new shortcut to the desktop.

Upon starting *Australis*, either an existing project may be opened or a new project created. An existing project may be opened from the FILE | OPEN menu. If the project has been opened recently, it may be reopened by selecting it directly from the *Most Recent File* list, which appears at the bottom of the FILE submenu. The *Most Recent File* list retains the last four projects that have been open. To create a new project, select the FILE | NEW menu item. A blank project template appears.

An *Australis* project filename has an *aus* (**aus**tralis project file) extension. To open project files directly from Explorer, the extension *aus* must be associated with the *Australis* executable.

1.5 User Interface

The *Australis* user interface consists of a **Project View, Image View**, and **3D Graphic View**. The Project View (Fig. 1.1) consists of a *Windows Explorer* style interface with a tree view on the left and a list view on the right. The tree view contains the Camera and Scale bar Database at the top and the current project information below. The list view displays detailed information about the selected item in the tree view. The Image View displays the selected image (Figure 1.2).

Points, camera stations, and scale bars are displayed in the 3D graphic view (Fig. 1.3). Additional functionality such as best-fit planes, spheres, and lines, and point-to-point distances is available here. The graphic view is discussed in detail in Chapter 7.

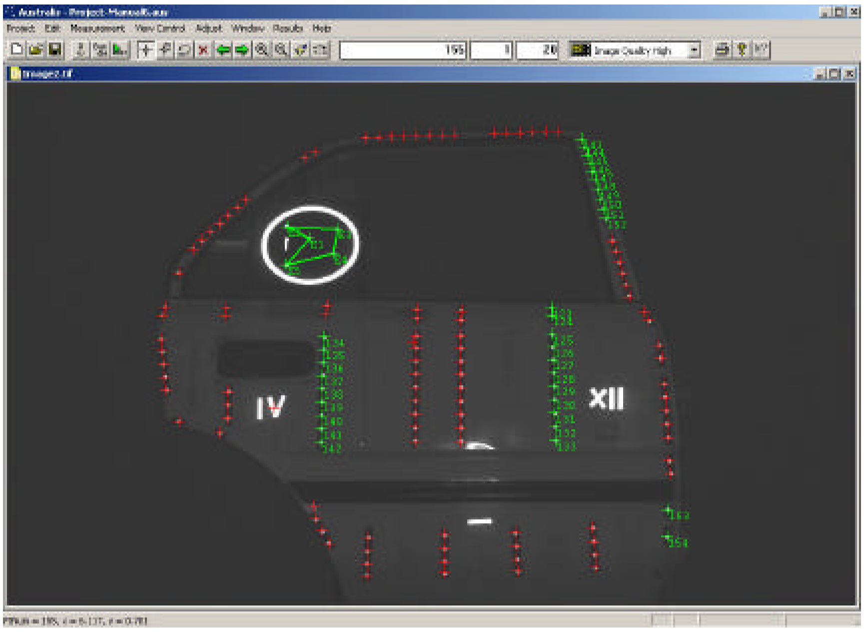


Figure 1.1: Australis image view.

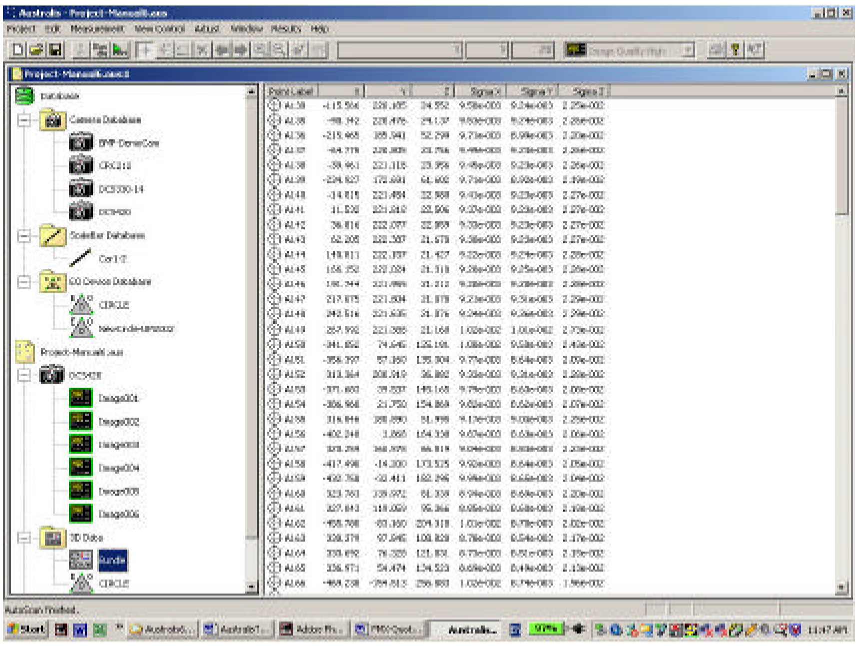


Figure 1.2: Australis project view.

1.6 Camera and Scale Bar Database

The Camera, Scale bar and EO Device Database stores calibration information for all available cameras, scale bars and Exterior Orientation (EO) Devices. This data is stored in the *Australis.ini* file. If any parameters are modified they are overwritten in the *ini* file when the program closes. Database cameras, scale bars or EO devices can be added, removed or edited in *Australis*, as described in Chapter 2.

1.7 Projects

All project data is saved in a single *Australis* project file (*projectname.aus*). This file contains all camera, image, and observation data. A project file may be reopened later to continue working on the same network. Projects are described further in Chapter 3.

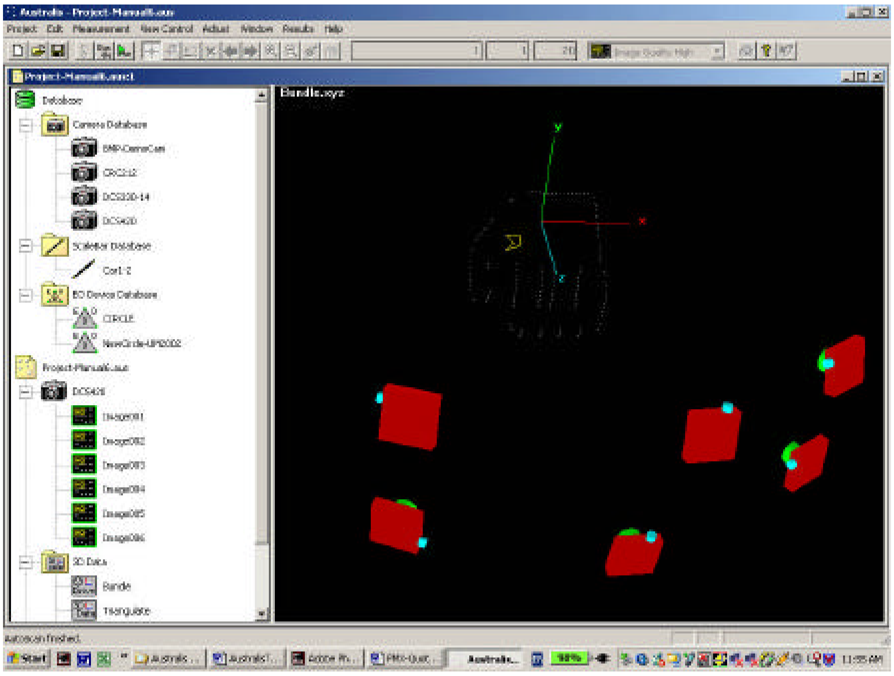


Figure 1.3: Australis 3D Graphics View.

1.8 Images

A primary function of *Australis* is to display digital images and measure points of interest within those images. An image is typically measured as part of a network orientation/triangulation project. Image manipulation and management is described in Chapter 4. *Australis* is presently designed to operate with black&white (8-bit) imagery and will accommodate the image formats of BMP, Tiff and JPEG. In the case of JPEGs, the program creates a local 8-bit B&W Tiff copy in the project directory for each JPEG image. These local Tiff files are left in the project directory and will subsequently be read in further runs of *Australis*. A description of the image coordinate system is provided in Appendix B.

Although Australis may function normally with colour imagery, it has not been designed to support colour and so full functionality of some features cannot presently be guaranteed. It is highly recommended that colour images be first converted to black & white, either as part of the normal Australis image-conversion or via an external conversion means (with Photoshop, for example).

1.9 Network Orientation and Bundle Adjustment

When targets have been observed in two or more images, the 3-dimensional coordinates for the targets can be determined using photogrammetric orientation procedures. Within *Australis* there are effectively two orientation phases. The first is preliminary orientation, which is via either relative orientation or resection/ intersection, and the second is final (refined) orientation which uses a least-squares bundle adjustment. If a self-calibrating bundle adjustment is performed, camera interior orientation and lens distortion parameters are also computed. The orientation procedures and bundle adjustment are described in Chapter 5.

1.10 Post Orientation Processes

There are a number of operations that can be performed on the photogrammetrically determined XYZ object point coordinates within *Australi*s. These include setting coordinate axes, performing 3D transformations, carrying out selected best-fit functions (eg line and circle) and exporting the XYZ coordinates in DXF or ASCII format. These capabilities are mostly described in Chapters 7 and 9.

2. Camera, Scale Bar and EO Device Database

2.1 Cameras

2.1.1 Adding Cameras to the Database

To add a camera to the database, right click on the Camera Database icon in the project tree view, and select ***Add Camera to Database*** from the popup menu (Fig. 2.1). This displays the ***Camera Input*** dialog. The fields shaded in light blue (on the monitor) indicate the minimum amount of information about the camera that must be input. This includes the horizontal and vertical sensor size (in pixels), the horizontal and vertical pixel size (in millimetres), and the focal length (in millimetres). Enter the required minimal information (plus any other known values) and click Ok to save the camera to the database and close the dialog.

2.1.2 Fiducial and Reseau Points

Australis supports the capability to re-establish the interior orientation of scanned metric images with fiducial and reseau points (Chapter 8). For a metric camera, check Metric in the ***Camera Input*** dialog to display the **Import Fiducials** button and listbox (Fig. 2.1).

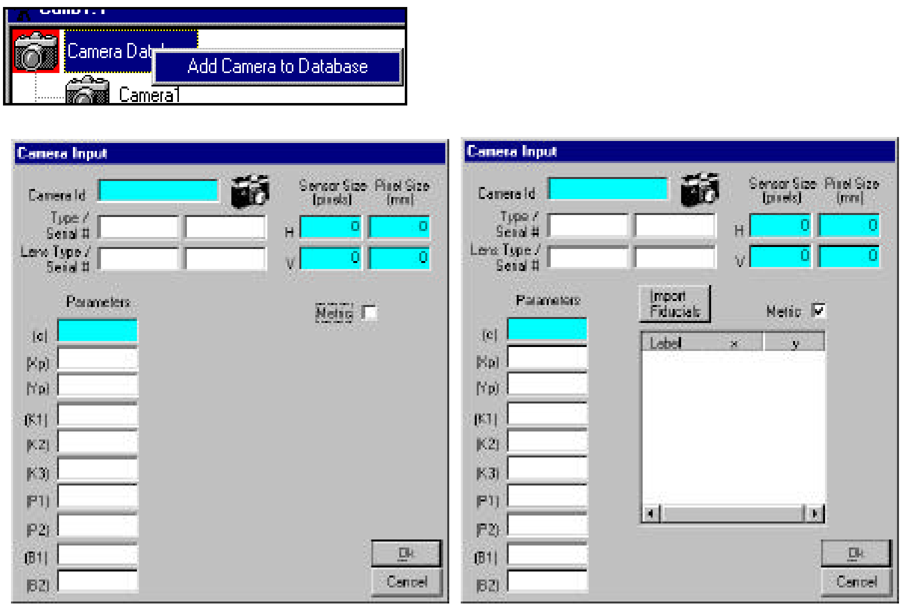


Figure 2.1: Adding a digital camera to the application database (left). Camera input dialog with fiducial import and editing (right).

Using the ***Metric*** button, fiducials may be imported from a file. *Australis* makes no distinction between fiducial and reseau points. As such, both must be placed in the same file. The file format is identical to that for image coordinate files given in Section 3.1.5. One point per line and each line has 3 fields; point number and x and y coordinates (in millimetres). Entries must be space delimited and point labels must be integers. Right clicking in the list box displays a popup menu with options to add, edit or delete points. Double clicking a point id in the list box displays a dialog to edit the point. One or more highlighted points may also be deleted with the **DELETE** key.

2.1.3 Removing a Camera from the Database

Highlight the icon of the camera to be deleted from the database and click the **DELETE** key. This action is permitted if the selected camera is in the current project, but it is not recommended. The user is prompted for verification before removal.

2.1.4 Modifying Camera Data

To modify camera data, double click on the desired camera icon. This displays the ***Camera Database*** dialog with an additional button used to save modified camera data (Fig. 2.2). Change any necessary parameters by double clicking in the appropriate box and typing in the new value. Fiducials may be added, deleted, or edited as

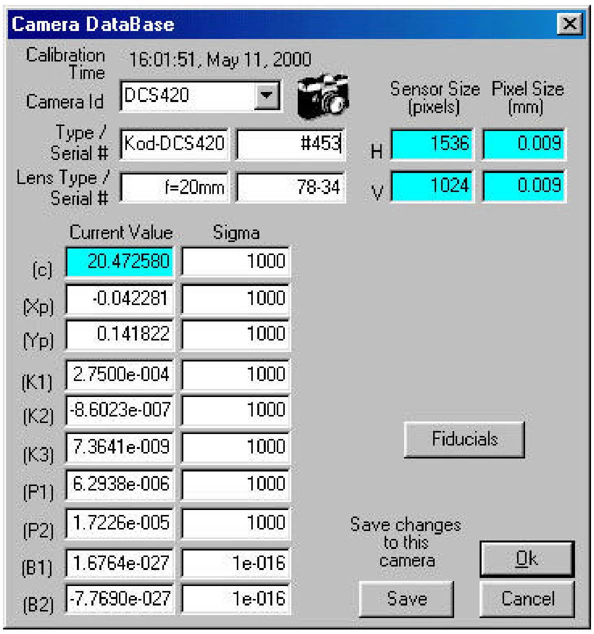


Figure 2.2: Modifying camera data

described in Section 2.1.2 by clicking the Fiducials button. When finished select the **Save** button. A message box verifies that the new values have been saved. When a camera in the database is being used with an opened project, the project camera data will not automatically replace that in the database unless the ***update camera in database*** option is selected (see Sect. 3.4)

2.2 Scale Bars

2.2.1 Adding Scale Bars to the Database

The procedure for adding a scale bar is similar to that for a camera. Right click on the Scale Bar Database icon in the project tree view and select ***Add Scale Bar to Database*** from the floating menu as shown in Fig. 2.3. This displays the ***Scale Bar Database*** dialog.

The minimal information that must be entered includes the scale bar name, the calibrated length (note this should be in the same units as the desired 3D object coordinates), the standard error (can be arbitrary if it is not to be used), and the labels for the end point targets. Note that if the scale bar is to be used rigorously as a point-to-point distance observation in the bundle adjustment, the standard error of the bar length must be included (see Section 5.1).

2.2.2 Removing a Scale bar from the Database

Highlight the scale bar icon in the database and press the **DELETE** key. The user is prompted for verification before removal.

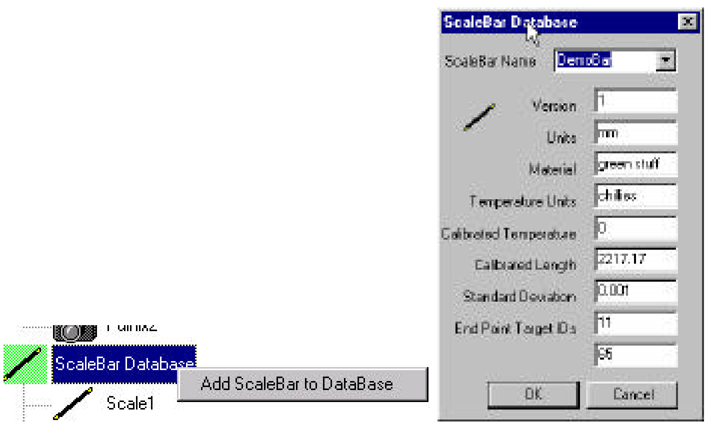
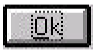


Figure 2.3: Adding a scale bar to the database.

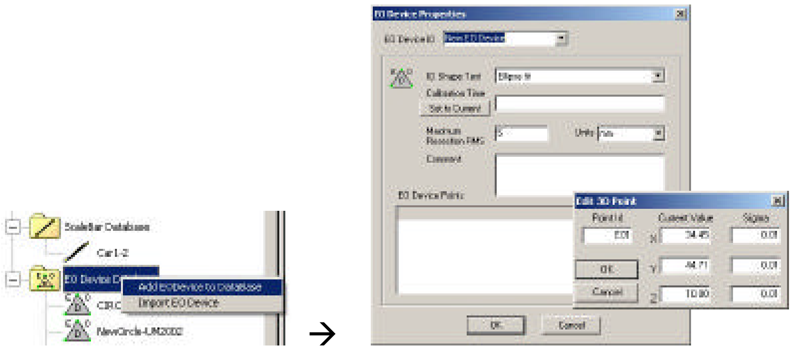
2.2.3 Modifying Scale Bar Data

Double-click on the desired scale bar icon. This again displays the ***Scale Bar Database*** dialog. Change any necessary parameters by double clicking in the proper box and typing in the new value. Click  to save.

2.3 Exterior Orientation Devices

2.3.1 Adding EO Devices to the Database

The procedure for adding an EO device to the database is similar to that for a scale bar. Right click on the EO Device Database icon in the project tree view and select either ***Add EO Device to Database*** or ***Import EO Device*** from the floating menu, as shown in Fig. 2.4.



or import an EO device

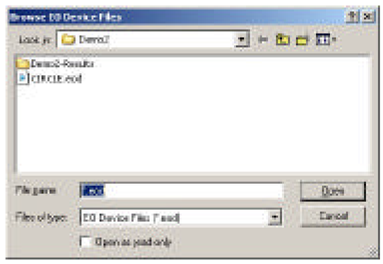


Figure 2.4: Adding an EO Device to the database.

The most important information to add in the EO Device Properties box are the EO Device name and the calibrated coordinates of the points (usually 5) on the EO device. To add point information, starting with the central point and working clockwise (see also Fig. 3.7), right-click in the points list box and select ***add point***. Values can then be entered as shown in Fig. 24. As the list of points is built, it can also be edited and points can be removed, again via a right-click and choosing the desired option.

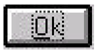
As an alternative to interactively adding the EO device point labels and XYZ coordinates, this information can be stored in an ASCII file, *name.eod*, and simply imported, the required format for each of the records in the EO device file (*.eod) being: *Point Label, X, Y, Z coordinates, all space delimited.*

Further information on EO devices is provided in Section 3.2.5 and 4.13.

2.3.2 Removing an EO Device from the Database

Highlight the EO device icon in the database and press the **DELETE** key. Or right-click and select ***Remove EO Device***. The user is prompted for verification before removal.

2.3.3 Modifying EO Device Data

Right-click on the desired EO Device icon and select Properties. This displays the ***EO Device Database*** dialog. Change any necessary parameters and click 

to save.

3. Projects

3.1 Cameras

3.1.1 Adding a Project Camera

A camera is added to the project by dragging its icon from the Database and dropping it directly onto the Project icon.

3.1.2 Removing a Project Camera

A camera is removed from the project by right clicking its icon and selecting ***Remove Camera From Project***, from the floating menu (Fig. 3.1). Or, highlight the camera icon and press the **DELETE** key. When a camera is removed, all images associated with that camera are also removed.

3.1.3 Adding Images to the Project

All project images **must** be kept in a single directory. To add images to the project, right click on the project camera and select ***Set Image File Directory***, from the floating menu (Fig. 3.1). The directory will be scanned for all images with a **tif**, **bmp**, **jpg** or **dib** extension. Images whose resolution matches the camera will be automatically included into the project.

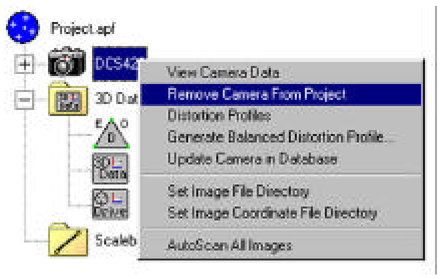


Figure 3.1: Removing a project camera

3.1.4 Removing Images From a Project

Remove a project image by right clicking its icon and selecting ***Delete Image*** from the floating menu (Fig. 3.2). Or, highlight the icon and press the **DELETE** key.

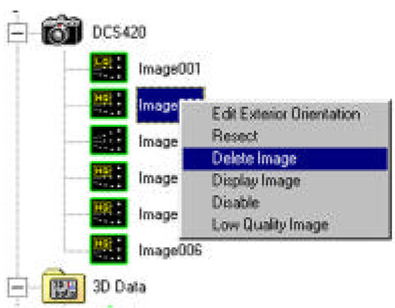


Figure 3.2: Deleting a project image.

3.1.5 Importing Image Coordinate Files

Image coordinate observations obtained from other photogrammetric image measurement systems can be processed with the *Australis* adjustment modules. This data is imported via individual files of measured image coordinates - one for each image to be processed. These files **must** have the extension **.icf* (**i**mage **c**oordinate **f**ile). The format of an image coordinate file is simple. Each line has 3 fields, the point label and x and y image measurement (in millimetres) for one point. Entries must be space delimited.

Importing image coordinate files is similar to importing images as described in Section 3.1.3. All image coordinate files **must** be kept in a single directory. Right click on the project camera and select ***Set Image Coordinate File Directory***, from the floating menu (Fig. 3.1). The directory is scanned for all files with a **.icf* extension.

Image icons for each file will appear under the camera icon in the tree view. When the camera icon is selected, image icons will also appear in the list view. All functionality for these icons is the same as has been previously described except that, because there is no *bmp*, *tif*, *jpg* or *dib* file associated with an icon, screen display of an image is not possible. However, the positions of the image points within the image format **will be displayed** when the icon is double-clicked, which allows the user to see where the points lie on each image. This is also very useful for running *Australis* when there is only a project file available. After **.icf* files have been successfully imported, all resection and bundle adjustment capabilities are available, as described in Chapter 5.

Note: Images and **.icf* files can be mixed within a project.

3.1.6 Display and Output of Distortion Profiles

Profiles for radial and decentring distortion are displayed by right-clicking on a camera icon and selecting ***Distortion Profiles*** from the resulting popup menu (Fig. 3.1). An example is shown in Fig. 3.3. The profiles are displayed to the maximum format distance, which is half the length of the image diagonal. The radial distance and corresponding distortion value are shown in the upper left of each window as the mouse is moved across the plot. As part of the self-calibrating bundle adjustment, the maximum radial distance of point measurements is recorded. If this value exists for the camera in question, it is displayed as a vertical red line. Beyond this point the distortion profile is seen as a dashed line. This indicates that the profile in this region is extrapolated, as no image points have been measured here. The plots are based upon the standard equations for radial and decentring distortion:

$$dr = K_1 r^3 + K_2 r^5 + K_3 r^7$$
$$P(r) = \left(P_1^2 + P_2^2\right)^{\frac{1}{2}} r^2$$

By right-clicking on the Project Camera icon, the operator can select ***Generate Balanced Distortion Profile*** (see Fig. 3.1). *Australis* will then create an output text file comprising a list of the Gaussian radial distortion, described for principal distance c by K_1, K_2 and K_3. Also output for an equivalent principal distance c_b is a listing of the 'balanced' radial distortion, which has zero distortion at a selected radial distance (usually at about 2/3rds maximum radial distance). The coefficients are $K^1{}_0$, $K^1{}_1$, $K^1{}_2$ and $K^1{}_3$. The operator is asked to interactively input the *balanced radius* (where distortion will be zero) as well as the radial *step* increments for the listing and the *maximum radial distance*. For example, for an image format of 15 x 10mm, an appropriate *balance distance* might be 6mm, the *maximum radius* 9mm and the *step* 0.5mm. The output file, *Balance.txt*, is stored in the project folder and a sample output is given in Sect. 13.6 (Appendix C).

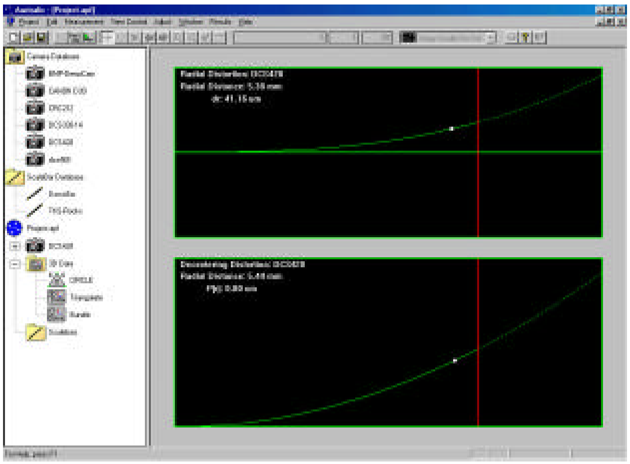


Figure 3.3: Camera radial and decentering profiles.

3.1.7 'High-Quality' and 'Low-Quality' Images

Images can be defined as High-Quality (HQ) or Low Quality (LQ). HQ implies high-contrast imagery with nominally circular/elliptical targets (preferably retro-reflective targets). Most industrial measurements would involve HQ imagery. LQ indicates imagery of lower contrast with less sharply defined targets. The HQ & LQ designations are used in the AutoScanning image measurement process to determine the amount of target validation and image processing required. LQ requires a more comprehensive testing of the targets prior to centroiding, and is therefore a little slower (see also Figure 3.8).

As shown in Figure 3.2, image quality is indicated by the presence of HQ, LQ or no quality indicator (meaning quality has not yet been set). Using the menu option indicated in Fig. 3.2 it is possible to toggle between HQ & LQ. This can also be achieved for multiple images by right-clicking on highlighted images in the project view listing & toggling between HQ & LQ. Finally, with the image display window open (Fig. 1.2), the image quality can be set via a pop-up menu on the main toolbar. **Note:** It is not necessary to explicitly specify an image to be HQ or LQ as the program will assign a value within the Autoscanning process.

3.2 3D Coordinate Data

Files of 3D coordinates may be imported, created and renamed within *Australis*. Additionally, points themselves may be edited, or added and deleted from files.

3.2.1 Importing XYZ Coordinate Files

3D point coordinate files must be imported into *Australis* for resection driveback (Section 4.11), for datum and redundant XYZ control, and for 3D coordinate transformation. These are imported directly from the project tree view (Fig. 3.4). Right click on the 3D Data icon in the project and select, for example, **Import | 3D Data File**, **Import | Driveback File**, or **Import | Control Points File**. This displays a File Open dialog from which the appropriate file is chosen.

If the imported file is not already in the project directory, a copy is placed there. The copied filename prefix is unchanged but the extension is set to *xyz*. If a file of the

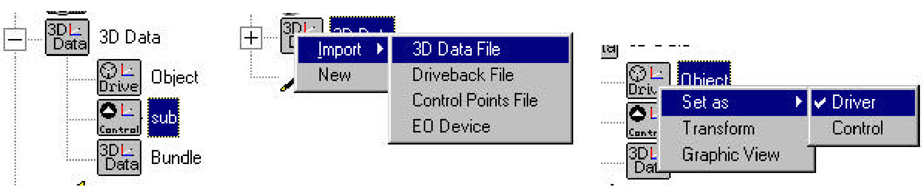


Figure 3.4: Project tree (left). Importing 3D files from project tree (centre). Setting file as driver or control (right).

same name is already in the project, the new filename is incremented. For example, if the file *Object.xyz* is already in the project and another file with the prefix *Object* is imported, its name is changed to *Object1.xyz*.

Once imported, 3D files are organised under the 3D Data icon in the project tree. There can be only one driveback and datum control file present at any one time. The driveback icon is characterised by a "steering wheel" and the datum control file icon by a control benchmark. Any file can be marked as driveback or control (or both) after import by right clicking on its icon and choosing Set as | Driver or Set as | Control. These settings can be toggled on and off as desired.

NOTE: As a precaution, when changing drivers, measured images are marked as "Not Resected" (the image icon border changes to red). All project images must then be resected again (Section 5.3).

To delete a 3D file from the project, highlight its icon and press the **DELETE** key. This action does NOT delete the file from the project directory.

3D files should be formatted as shown in Table 3.1. Each line contains the point label (alphanumeric or integer), XYZ coordinates and SX, SY, SZ sigma values. The sigmas are optional. Entries **must** be space delimited.

3.2.2 Creating An Empty 3D Coordinate File

To create an empty 3D file, right-click on the 3D Data icon in the project tree and select **New** from the menu (Fig. 3.5). A new, empty file is created in the project directory and its icon appears. The new filename is by default, *3DDataFile.xyz*.

Table 3.1 : 3D input file format.

11A	0.0142	-20.0702	38.5644	1.0e-16	1.0e-16	1.0e-16
Point12	497.8725	-5.6927	29.1525	1.0e-16	1.0e-16	1.0e-16
13	1000.6319	7.8336	37.7232	1.0e-16	1.0e-16	1.0e-16

3.2.3 Renaming a 3D Coordinate File

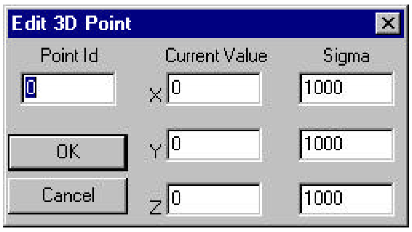


Figure 3.5: Point edit dialog.

To rename a 3D file, click on the text of its icon with the left mouse button. A second click enables this text to be edited (Fig. 3.5 - **Note**: this is not a double click. The sequence is click, pause, and click). Rename the file and hit the *Enter* key. The file is renamed with the new prefix. The extension remains *xyz*. A warning appears if the new file already exists and provides an option to replace it. If the new file is already in the project, the name will be incremented as described in Section 3.2.1.

3.2.4 Adding, Deleting, Editing and Renaming 3D Points

To add a point to a 3D file, first highlight the file icon in the project tree. Then, right click in the list view on the right side of the screen. Choose **Add Point** from the popup menu (Fig. 3.5). This displays the Point Edit dialog (Fig. 3.6). Enter the necessary data and click the **OK** button. Individual point characteristics can also be edited directly by clicking (*click*, *pause*, *click*) on the desired column. A small edit box is displayed in which changes may be made. Upon clicking outside the edit box or using the Enter key, the value is updated and saved. A priori coordinate standard errors can be edited only for points designated as control.

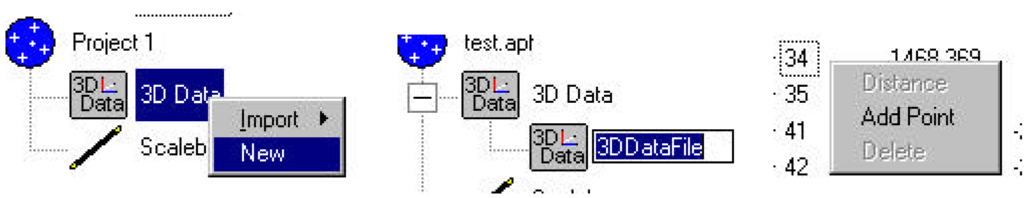
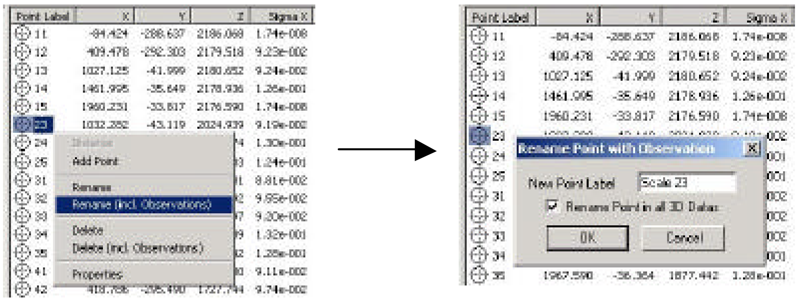


Figure 3.6: Adding an empty 3D file (left). Renaming a 3D file (centre). Adding or deleting (right).

To delete points from a 3D file, again highlight the file icon in the project tree. In the right side list view, select the points to be deleted. Right click and choose **Delete** from the popup menu. Or, simply hit the delete key.

To edit a 3D point, double click on the point icon in the right side list view. This again displays the point edit dialog from which data may be changed (Fig. 3.6).

A very useful feature is the ability to rename or re-label a point in the object point list, and also possible to re-label all observations associated with that point. To do this, single-click on the **Bundle** icon in **3D Data** to list the XYZ coordinates and then right-click on the desired point label.



This feature is very useful, for example, in introducing scale control, where the labels of the two end points of a scale bar in the scalebar database can be assigned to the appropriate points in the object field, along with all their corresponding observations.

3.2.5 Exterior Orientation Devices

An Exterior Orientation (EO) device is an object that facilitates determination of sensor exterior orientation (either manually or automatically) when no coordinate data is available for the target field. A typical device has a minimum of five well-distributed targets with known coordinates (Figure 3.7). The standard approach would be to measure a minimum of images (at least three) which see all or most of the target array, including the EO device. After these images are measured, the bundle adjustment yields coordinates for all targets (see Chapter 5). This process can be performed automatically if an appropriate EO device is employed. For automatic EO device detection and measurement, *Australis* currently requires an EO device design as indicated by the left-hand image in Figure 3.7. The *Australis* EOD requires that all points are located within a bounding 'ring', but this figure can be any shape. A circle, rectangle, square or triangle are all acceptable.

To ensure that the automatic measurement of the EOD is as fast as possible, label the points in ascending numerical order from the centre point, then clockwise for the 'outer' points. This is not mandatory, but it represents the default labelling scheme for maximum performance.

Figure 3.7: Representative EO devices.

There is now an EOD database, in much the same way as there was previously just a camera and scale-bar database. The data for each EOD can be entered manually (coordinates entered via right clicking in the coordinate list area) or simply by importing an EOD file in the normal way via the **3D data** icon, and then dragging and dropping it into the EOD database.

A file of EO device coordinates *must* have an ***eod*** extension. The file format is identical to that described in Table 3.1. Importing an EO device file is done as shown in Figure 3.4. However, only one EO device may be in the project at any one time. If a new EO device file is imported it will replace any existing device file. The semi-automatic EO device measurement procedure is described in Section 4.13 and fully automatic measurement and orientation/triangulation is covered in Chap 6.

As with cameras, an EO Device is added to the project by dragging its icon from the Database and dropping it directly into the Project.

3.2.6 Exporting 3D Coordinate Data in DXF Format

As a standard operation in *Australis*, all 3D data files are saved in ASCII format within the Project Folder. They are thus fully accessible following an *Australis* run. To aid in the importing of 3D coordinate data into CAD systems, *Australis* also supports export of 3D data files (nominally comprising records of label, X,Y,Z and three additional fields) in DXF format.

To export a data file in DXF format, right-click on the desired icon in the *3D Data list* and elect **Export as DXF.** A DXF file will then be written with the same name (name.dxf) to the project folder.

3.3 Scale Bars

3.3.1 Adding a Project Scale Bar

As with cameras, a scale bar is added to the project by dragging its icon from the Database and dropping it directly into the Project.

3.3.2 Removing a Project Scale bar

Select the scale bar icon and press the **DELETE** key.

3.4 Saving Projects and Camera Data

3.4.1 Projects

To save a project select either **Project | Save** or **Project | Save As** from the main menu, or click the floppy disk button on the toolbar. By default, *Australis* project files are given an *aus* extension. (e.g. *Demo2.aus*).

3.4.2 Updating Camera Database

If upon completion of a project it is desired to update the camera calibration parameters within the camera database, the **Update Camera in Database** option can be selected from the menu generated by right-clicking on the project camera icon (Fig. 3.1). Alternatively, the project camera can be 'dragged and dropped' into the database.

3.5 Project Preferences

To edit project preferences choose **Project | Preferences** from the main menu. This displays a *tab* dialog from which preferences may be set for the project, adjustment output, image point numbering, and digitising (Fig. 3.8).

3.5.1 Bundle Adjustment Output Preferences

This form determines bundle adjustment output. In addition to the standard bundle file, the options to output coordinate residuals and adjusted camera parameters are checked by default. Parameter correlations may also be output. The output of EO rotation matrices in the standard bundle file is optional as is the output of omega, phi, kappa rotation angles (azimuth, elevation, roll angles are always calculated).

3.5.2 Image Preferences

If the *Number Points* box is checked, point labels are drawn on the image upon measurement. Point labels are recorded in the project, regardless of this setting.

The *Shape* radio buttons determine whether a blob or a cross will be drawn on the image over the target points.

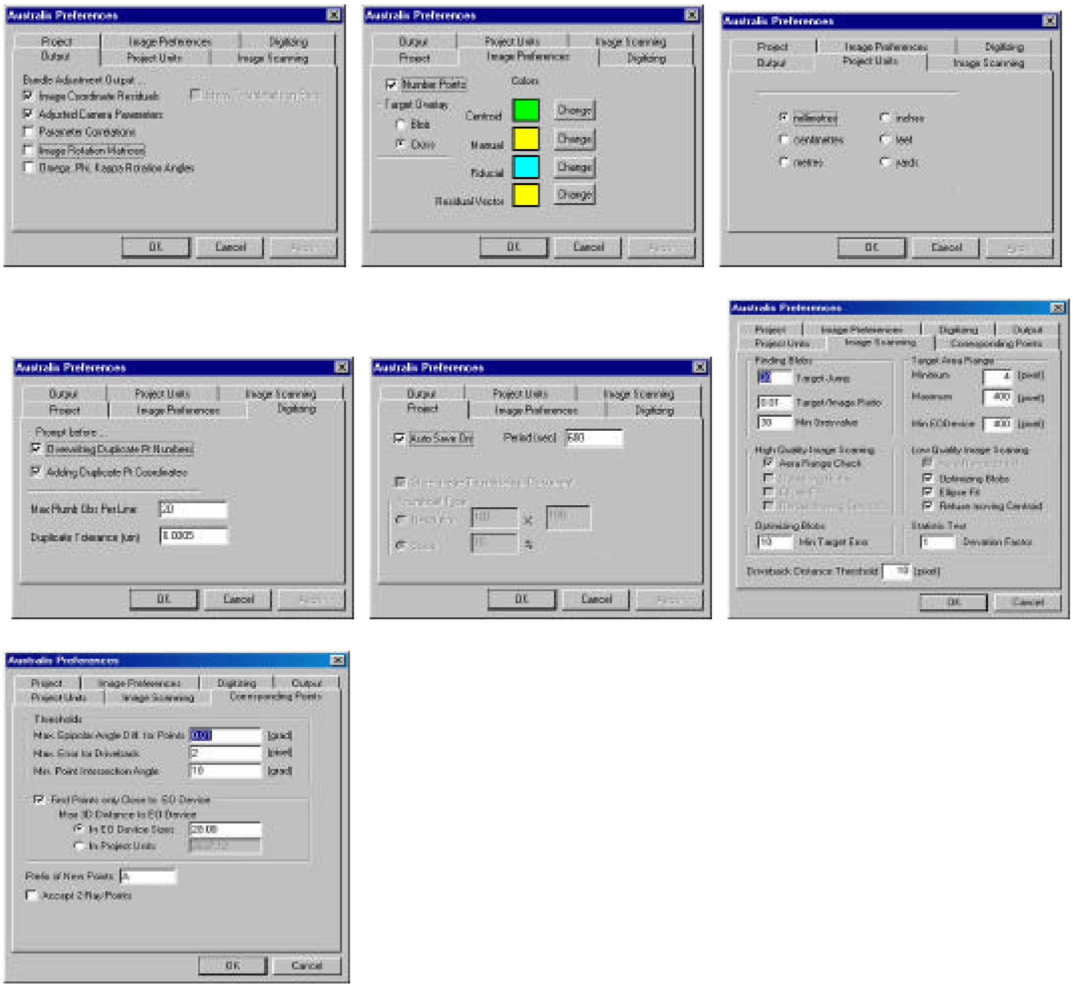


Figure 3.8: Output, image, units, digitising, project, scanning & point correspondence preference boxes.

The *Point Colour* setting determines the colour of the observations drawn on the image. Different colours can be set for points that have been measured manually, or by centroiding. Colour for fiducial points can also be set. Residual vector colour is also set here. To change any of these settings, click the appropriate *Change* button and select a new colour from the resulting Color Dialog box.

3.5.3 Project Unit Preferences

When starting a new project, the user is first prompted for project units. Choices are millimetres, centimetres, metres, inches, feet, or yards. The project units can be changed at any time through the Project Unit Preference tab. Any 3D files in the project are automatically updated to reflect a change in units. The exterior orientation of any camera stations which have been resected is also modified.

3.5.4 Digitising Preferences

The *Prompt Before Overwriting Duplicate Point Numbers*, and *Prompt before Adding Duplicate Pt Coordinates* check boxes determine whether or not the user will be asked before any such observations are replaced. The threshold for determining whether two observations have identical coordinates is set in the *Duplicate Tolerance* box (in micrometres).

Max Plumb Obs Per Line determines the measurements made automatically along an individual plumb line (Section 4.7).

3.5.5 Auto-Save Project Preferences

The Project Preferences currently only include characteristics of the Auto-Save feature. Auto-Save is enabled by default and the default time interval is 10 minutes.

3.5.6 Image Scanning Preferences

Automatic image scanning is discussed in Section 4.3. Scanning preferences include parameters which control the finding and validation of targets within an image. There are specific parameter sets for High-Quality and Low-Quality images.

Note: Default values are generally applicable.

Parameters of interest include the minimum and maximum number of pixels in a valid target region (*target area range*). These are set at 4 and 200 by default. Extremely large targets will require a larger maximum number of pixels. Also, the **Driveback Distance Threshold** is set at 10 pixels by default. This value controls the distance within which a target is positively identified in resection driveback (Section 4.11).

A very brief account of other parameters is as follows:

Finding Blobs: *The Target Jump* is a greyvalue step above which a blob is assumed to be present; the *Target/Image ratio* indicates the ratio of the blob intensity range to the full intensity histogram for the image; and the *Min Greyvalue* indicates the lowest intensity that a blob needs to have to be recognised as a potential target.

Target Area Range: Simply expresses size limits on targets, including those of the EO device.

High- and Low-Quality Image Scanning: The Area range check in the HQ image scanning is as per above. In the LQ scanning, *optimizing blobs* removes all pixels which are beyond a certain multiple of standard deviations from the mean. This same multiple is given by the *Deviation Factor* in the **Statistic Test** box. Irrespective of the sigma value, *Min Target Error* will also apply. The *ellipse fit* is a shape qualifying function, and *Refuse moving centroid* indicates that a target will be disregarded if its centroid determined in the optimisation/ellipse fitting differs by more than a certain threshold from the centroid determined by the refined intensity weighting algorithm. Recall that only LQ images undergo blob optimisation and shape testing.

3.5.7 Preferences for Point Correspondence Determination

Initially, there are three thresholds relating to the tolerances of multi-ray intersection within the image point correspondence determination process, which commences with a point matching via the measurement of angular departure from an epipolar plane. The default threshold for the *Max. epipolar angle diff. for points* is 0.01 grad. After matches are found in two images, a resection driveback approach is employed for the search for candidate points in other images. The threshold value for this search, *Max. error for driveback*, has a default value of 2 pixels. The final threshold relates to the minimum acceptable angle between two candidates for corresponding rays, *Min. point intersection angle*, which has a default value of 10 grad.

Within the preferences for image point correspondences, it is possible to set a letter or word prefix for autoscan points, *Prefix of new points*. Also, there is a box to be checked if it is desired to accept 2-ray points. Otherwise only points with three or more rays will be considered.

Finally within this set of preferences there are tolerances related to the search distance beyond the EO device. Candidate image points will only be considered if they are either within so many *EO device sizes* (eg 10-20) or within a given distance in object space, *in project units.*

3.6 Project List View Functionality

As mentioned previously, the right side of the project view is a list display that lists cameras, images, observations, or 3D points depending on what is selected in the left side tree view. Limited functionality is available from this view. If cameras or scale bars are displayed in the list view, double clicking on an icon will display the data for that item. If image icons are displayed, double clicking an icon displays that image.

When 3D points are displayed, double clicking an icon displays a dialog for editing that point. Point-to-point distances can be computed if exactly two points are selected. Right click on one of the selected points and then click on **Distance** in the resulting pop-up menu. The distance is displayed in a message box. This distance is not saved to a file.

3.7 Relinking Project Images after Changing Project Folders

It is often required that a project file (*project.aus*) be moved to another folder or even another computer. Upon opening the project in the new location it will be found that there are no associated images since *Australis* will look for these in the original project directory. The program allows a 'relinking' of images to the project in such a situation.

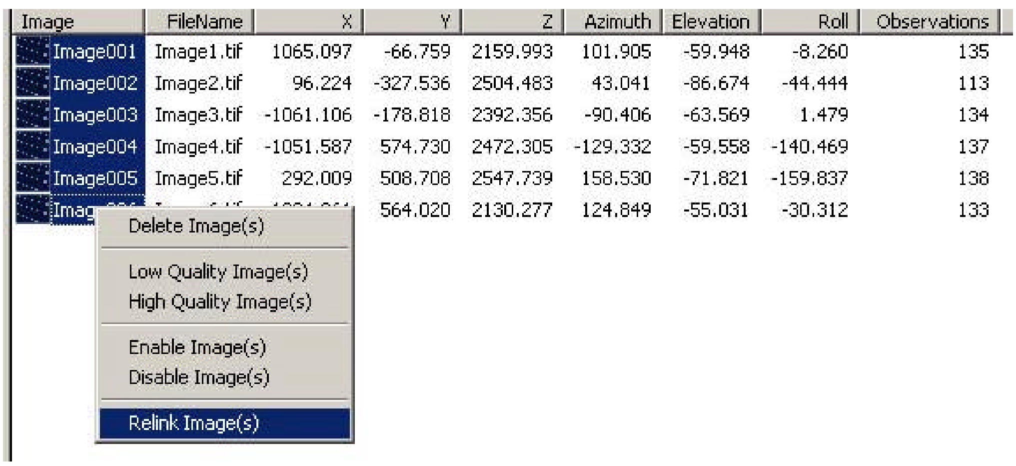


Figure 3.9: Choosing to relink images to project after a project.aus file is moved toanother directory.

First, expand the list of images such that the image names and exterior orientation are indicated as shown in Figure 3.9. Next, select the images and right click on the selected list. Within the list of options select the ***Relink Image(s)*** option.

A screen message them informs the operator that the images must have the same names in the new directory, and that directory is then selected. Finally, a screen message will indicate how many images were successfully relinked.

4. Image Handling and Measurement

4.1 Opening Images

Double click the image icon in either the project tree or the right side list view. Or right click on the image icon in the project tree and select **Display Image** from the floating menu (Fig. 3.2). Remember, that if you are using image coordinate files or running an *Australis* project from the **.aus* file without images, the image point locations will still be displayed in the image view.

4.2 Centroid Measurements

To observe targets in an image, the application must be in *digitise* mode. Click the *cross-hair* icon on the main toolbar or selecting **Digitise Mode** from the **Measurement** menu. When in *Digitise* mode, this menu item will be checked and the cursor appears as a cross hair within the image window. Observations are made using either centroid or manual measurement. To use centroiding on suitable targets, ensure that **Auto** from the **Measurement** menu is checked (this is the default setting). Repeated selection of this menu item will toggle centroiding on and off (Fig. 4.1).

To make an observation using centroiding, place the cursor near the center of the target being observed and click the left mouse button. The centroid algorithm uses the raw coordinates of the mouse click as a starting point. The coordinates of the target centroid are saved. Thus, it is not necessary to be very accurate with mouse pointing for automatic centroiding, as opposed to manual measurement

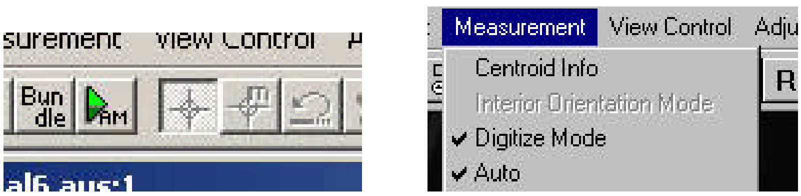
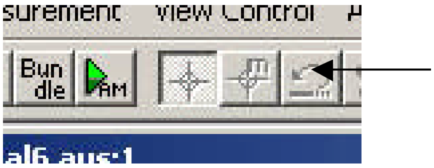


Figure 4.1: Settings for centroid measurement and digitise mode.

Manual image point measurement can be alternatively initiated via a button on the toolbar. In order to set the Manual option, the image measurement button must be already selected (Fig. 4.1). Manual measurement is then invoked by simply clicking the second measurement button on which there is an 'M'. It should be remembered that manual measurement (yellow point labels) is not recommended in circumstances where the imagery has good targets which are suited to the more accurate automatic centroiding. It is, however, useful for natural features.

Note: The button to the right of the Manual Measurement button in Fig. 4.1 has an 'undo function'. If this button is clicked, the previous image measurement is deleted. Clicking it twice deletes the last two measurements and so on.

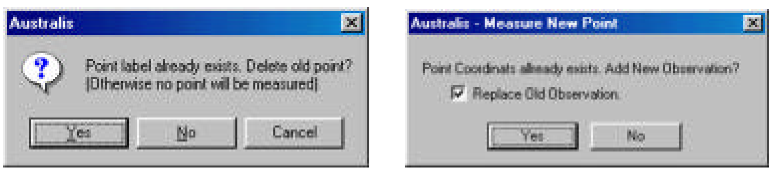


Delete previous image point measurement

A description of the pixel and image coordinate systems is provided in Appendix B.

The centroid algorithm used will vary according to the settings chosen by the user (Section 4.2.1). Different centroid algorithms will work best with different types of targets, and settings such as the optimal centroid window size may vary for each image.

If an observation is given a label that has been previously used, or if two observations are made to the target, the warnings displayed in Fig. 4.2 appear. Answering *Yes* in Fig. 4.2a will replace the previously measured point with the newest point having the same label. Where what is obviously a measured point is attempted to be measured a second time with a different point label, the warning in Fig. 4-2b appears. Answering *Yes* & unticking the box has the effect of allowing the same observation to have two different labels & therefore to be treated as two different points. (It is rare that such an action would be required.)



(a) *(b)*

Figure 4.2: Warnings indicating duplicate point locations or labels.

4.2.1 Centroid Parameters

Centroiding parameters can be set using the **Centroid Info** item on the Measurement menu (Fig. 4.3). Each of these parameters is now addressed along with the error message that can arise from an incorrect setting.

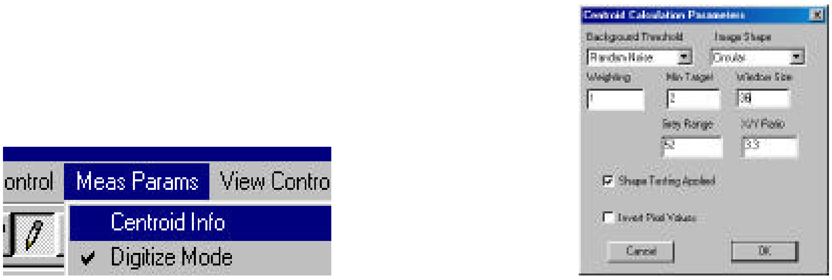


Figure 4.3: Setting centroiding parameters.

Window Size: Sets the size of the window in which the target must lie (must be < 128 pixels). If the targets are too big for the window the error is *Centroid Window Out of Range*. The Centroid Window Size can also be set in the third edit box of the main toolbar (Fig. 4.4).

Figure 4.4: Setting centroid window size from the toolbar

Grey Range: Specifies the minimum range of intensity in the centroid window. This parameter is a way to ensure the target stands out against the image background. If this criterion is not met, there will be an error message: *Intensity Range too Low*.

Min Target: Sets the minimum size in pixels for centroiding. Attempting to centroid a target below this minimum will result in the message, *Image Size is too Small*.

X/Y Ratio: Specifies the size ratio of the centroiding window. During centroiding the window is shrunk around the target. This parameter is used maintain a square window shape. If the ratio is exceeded it is likely that the target shape is not elliptical and an *Image Shape Error* message results.

Image Shape: Used to predetermine the target shape. Target shape is typically elliptical, however lines can also be centroided. If the *Shape Test Applied* box is checked, target shape will be verified. Failure produces an *Image Shape Error* message.

Invert Pixels: When this box is checked the pixels in the centroid window are inverted. The target must be a high intensity feature with a relatively low intensity background.

Background Threshold: Selects the type of thresholding used. Options include additive, scale and preset values. An explanation of thresholding is beyond the scope of this manual - if in doubt use the random option. The differences in observed coordinates from the various thresholding algorithms are generally in the order of 0.03 pixels or less, which is generally negligible in the bundle adjustment.

Weight: Although this value can be zero, one or two, **one** is advised and is the default. The centroid algorithm calculates the weighted mean centroid, and this value effects the weight given to each pixel. The weight indicates the power to which each pixel value is raised in calculating the centroid. Zero is appropriate only for binary images.

4.3 Image AutoScan

Images are automatically scanned for valid targets using the *AutoScanning* functionality. AutoScan runs from within the Image View by choosing the **AutoScan** item from the **Measurement** menu or by using the key combination ALT+A. All images can be scanned by right clicking on a project camera in the Project Tree View and selecting **AutoScan All Images** from the popup menu (Fig. 3.1). For **AutoScan All Images** the AutoScanning dialog is displayed and scanning is started with the **Start Scan** button. Actual target measurement is accomplished by centroiding.

If an *Australis*-compatible EO device is included in the project (and the **.eod* file is entered into the project), the AutoScanning will search for and measure the EO device and carry out a space resection for exterior orientation, for either one image or all images. Thus, at the end of AutoScanning the preliminary exterior orientation of the network is established.

Scan points are displayed on the image without labels. In the Project List View, a red (default colour) icon differentiates autoscan points from labeled points. Additionally, labels are prefaced with a letter or word of your choice (see Sect 3.5.7). Scan points are not used in the Resection or Bundle Adjustment functions until they have been labeled, for example after automatic image point correspondence determination or after manual labelling, or following resection driveback. Labeling is done from the Image View in a manner similar to that for point centroiding described in Section 4.2. The application must be in *digitise* mode. The mouse cursor is placed on or near a scanned point (within the current window size as shown in Fig. 4.4). The current window can be visualised in the image with the Magnified View Window (Fig. 4.6). There must be only one scan point within the window for labeling. If there are multiple scan points within the window, no action is taken. If a Driveback file is present, Resection Driveback (Section 4.11) can be performed after a minimum of four scan points has been labeled.

4.4 Manual Measurement

As per the description in Section 4.2, the first step of Manual Measurement is to ensure that the Manual Measurement button on the toolbar is selected, along with the main 'cross-hair' button. In this case, image coordinates are calculated directly from the mouse position within the image window. Manual measurements can be sub-pixel, depending on the current zoom factor. Zooming is as per Figure 4.5 and is described below.

Note: To enter a point label with the image view open, simply start typing on the keyboard or use the point label box (the large, left-most box) on the toolbar (see Sect 4.10).

4.5 Image View Control

To increase the accuracy of manual measurement, the user may zoom in around targets. Select **Zoom In** or **Zoom Out** from the **View Control** menu. Or, press the toolbar button with the + or - magnifying glass (Fig. 4.5).

In Zoom mode, the cursor is a magnifying glass. To zoom in or out about a point, move the cursor to the area and click the left mouse button. The image can be refreshed to its original size by choosing **Full Image View** from the **View Control** menu or pressing the *paintbrush* button on the toolbar.

Figure 4.5: Zoom mode.

4.6 Magnified View Window

The Magnified View Window (Fig. 4.6) displays the area of the image that is currently beneath the mouse pointer or cross hair. The displayed area is twice the size of the current centroid window while the green border represents the centroid window itself. This window can be useful in differentiating individual targets in dense clusters. Activate the window using the menu command **View Control | Magnified View**, or the key combination **ALT + M.** Note that there is a cross in the middle of the window to aid in precise manual point measurement.

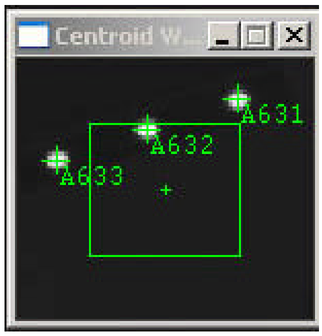


Figure 4.6: Magnified view window.

4.7 Image Brightness

Image brightness is adjusted by right-clicking in an open image, and selecting one of the menu items on the Brightness sub menu (Fig. 4.7). Image brightness can also be changed using the ↑ and ↓ keyboard arrows (make sure the image view is the active window). Note that altering the image brightness affects the screen display ONLY and does not change pixel values within the image in memory.

4.7.1 Histogram Stretch

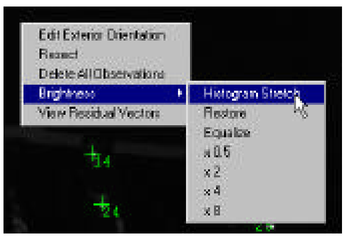


Figure 4.7: Altering image brightness.

The Histogram Stretch function uses the mean and standard deviations of the raw pixel values to determine a pixel range over which to stretch the image. The formula used to calculate the range is mean +/- 2*standard deviation. This assumes that the frequency of the raw pixel values within the image form a "normal" distribution, which is generally not true, however the result is suitable for most images. Pixel values within the histogram range are scaled between 0 and 255, while all values less than the range are set to 0 and all values greater are set to 255.

4.7.2 Restore

The Restore function returns the image to an unaltered display state.

4.7.3 Equalize

The Equalize function stretches the visible image pixel values between 0 and 255. This is useful when there is very little contrast in the image, or when the image is either under or overexposed. When utilising retro-reflective targets, the Equalize function may have little or no effect because the pixel range is already approximately 0 to 255. This is because the background is generally very dark while the targets are bright.

4.7.4 Multiply By *x*

The Multiplication functions simply multiply the raw pixel value by the scale factor, with minimum and maximum values of 0 and 255.

4.8 Viewing Residual Vectors

Image coordinate residual vectors are displayed by the "v" key, which toggles the vector display on and off. The vectors are initially multiplied by a display scale factor of 500 for visibility. The "Alt *plus* =(+)" and "Alt *plus* -(_)" key combinations increase or decrease the scale respectively. The current display scale factor is displayed on the right side of the status bar at the bottom of the screen. Vector colour is set on the Image Preferences Sheet of the Project Preferences dialog (Section 3.5.2). Residual coordinates of rejected points are always displayed in red. An image with residual vectors is shown in Fig. 4.8.

Figure 4.8: Image with residual vectors.

4.9 Plumb Lines

Plumb line images are typically used to model radial lens distortion. Plumb lines that are nearly horizontal or vertical can be measured in *Australis*. To activate *plumb line measurement mode*, select **Measurement | Plumb Line**, then select either VERTICAL or HORIZONTAL (Fig. 4.9). When in Horizontal or Vertical Plumb line mode the cursor is a cross hair with the letters HP or VP respectively.

To measure plumb lines, click the left mouse button on a point at the start of the line and a second point further along the line to establish the measurement interval. Measurements are then made automatically along the line at this interval. Image coordinates can then be written to a file via the **Output Observations** facility in the **Measurement** menu (Section 4.14).

Figure 4.9: Plumb line measurement mode.

4.10 Point Labelling / Point Increment

Integers and alphanumeric character strings (to 12 digits) are acceptable for image point labels. The point label is set in the leftmost edit box in the main toolbar (Fig. 4.10). The point increment, which operates on the right most digit of the label, may be either a positive integer (for numbers and characters) or negative integer (for numbers only). These values are changed by double clicking inside the edit boxes and inserting the desired values.

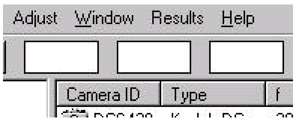


Figure 4.10: Edit boxes in the main toolbar are for point label, point increment, and centroid window size respectively.

Note: Point labels can also be input by simply typing on the keyboard when the image view is open; it is not necessary to click within the edit box.

4.10.1 Skip Point

To increment the current point label by the point increment, use the Skip button on the tool bar or the ALT + S key combination (Fig. 4.11).

4.11 Resection Driveback

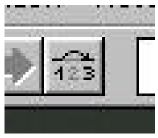


Figure 4.11: Skip point.

Resection driveback provides a semi-automated method of target measurement. Reasonable approx. 3D point coordinates for the 'control' targets (4 or more) must be available.

Resection driveback steps are as follows:

- Ensure that a file of 3D resection control coordinates is imported (Chap. 5).

- Measure a minimum of 4 well-distributed points throughout the image, ensuring that the points are labeled correctly. Select the **Driveback** item from the **Measurement** menu, use the toolbar button marked with a **D** over a benchmark symbol, or use the key combination **ALT** + D (Fig. 4.12).

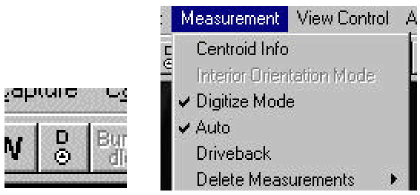


Figure 4.12: Resection driveback.

The driveback function first performs a resection to determine the camera station exterior orientation. By default, a *closed-form* resection is used and initial XYZ camera station coordinates are computed automatically (Section 5.2). If the closed-form fails, the user may provide initial coordinates.

If the resection is successful, the resulting exterior orientation and the 3D object point coordinate parameters are used to determine the approximate image locations of all targets. A centroid measurement is attempted at each of those positions, and successful measurements are stored. Following the resection, a message box displays the RMS of the image coordinate residuals. If this value appears unreasonably high, the driveback may be prevented by choosing **No** from the message box (Fig. 4.13).

Figure 4.13: Confirming resection driveback.

A large RMS image coordinate error value may suggest: 1) one or more points have been incorrectly numbered, 2) initial camera position coordinates are grossly incorrect, or 3) the camera calibration is poor. It is noteworthy, however, that a poor resection result may nevertheless still produce satisfactory semi-automatic image measurement.

4.12 Line Following

To measure regularly spaced points along a straight line, measure the first target and then measure the second while holding down the **SHIFT** key. Remaining targets are measured along the line defined by these two points. Point labels are automatically incremented. The distance between the two initial points determines the search angle and measurement interval.

4.13 EO Device Measurement

Australis-compatible EO devices can be measured fully automatically as part of the AutoScanning process (Section 4.3). All EO devices can also be measured semi-automatically according to the following procedure: The EO device measurement procedure is initiated in the image view by selecting **EO Device** from the **Measurement** menu or by using the hot key combination **ALT+E**. The cursor changes to a crosshair/triangle combination to indicate EO measurement mode. The first point label in the EO device file appears in the point label window on the toolbar. Red line segments are drawn connecting the EO device points as they are measured and labels are incremented accordingly in the point label window. When the last point is measured, the image is automatically resected. If the resection is successful, the connecting line segments change from red to green (Figure 4.14). The cursor then returns to the standard crosshair indicating standard measurement mode.

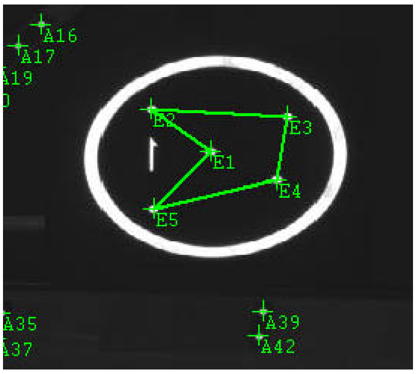


Figure 4.14: Successful EO resection.

4.14 Output of Image Coordinate Measurements

To output all measured image coordinate data to ASCII files, one need only click on **Output Observations** in the pull-down **Measurement** menu. The resulting files *imagename.icf* (one for each measured image) may be opened via Notepad. Each record in the files comprises three fields: point label, x and y, where the units are in millimetres.

4.15 Image Point Correspondence Determination

Following the AutoScan operation each image has effectively a point cloud of measured, unlabelled targets. The purpose of the Image Point Correspondence Determination is to find so-called homologous or matching points between the images forming the network.

Note: A prerequisite for this operation is a preliminary exterior orientation. Thus an EO must have been performed via either an EO device or via standard relative orientation or resection from a subset of driveback points.

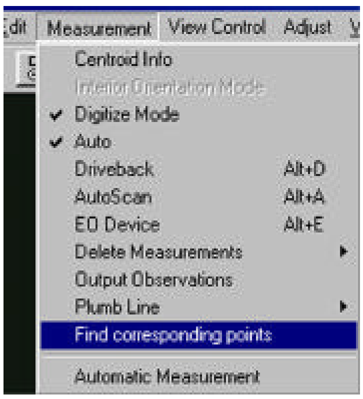


Figure 4.15: Point Correspondence Menu.

The **Find Corresponding Points** item is found in the **Measurement** menu, Fig. 4.15. Selecting this item will open the dialog box shown in Fig. 4.16. Individual parameters are defined in Sect. 3.5.7.

It is possible to select and deselect the images desired for inclusion in the point correspondence determination. Note that *resection driveback* is used as a component of this operation to make the process as robust and time efficient as possible.

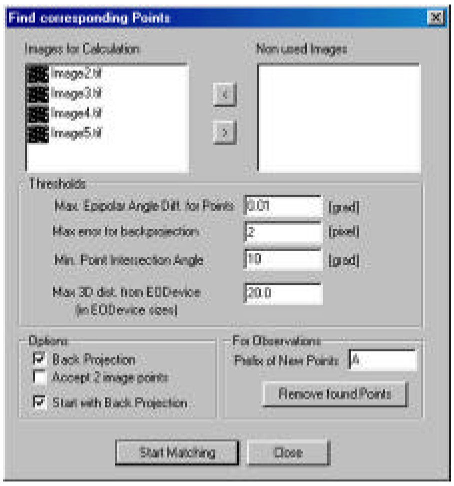


Figure 4.16: Preferences for point correspondence

4.16 Point Status Summary

The Point Status Summary is a feature to allow the user to ascertain the images and number of images upon which a particular object point appears and has been measured. Select the **Measurement Menu** and **Point Status** and the dialog box shown in Fig. 4.17 will appear. The desired point label can be selected and a list of images 'seeing' the measured point will be provided.

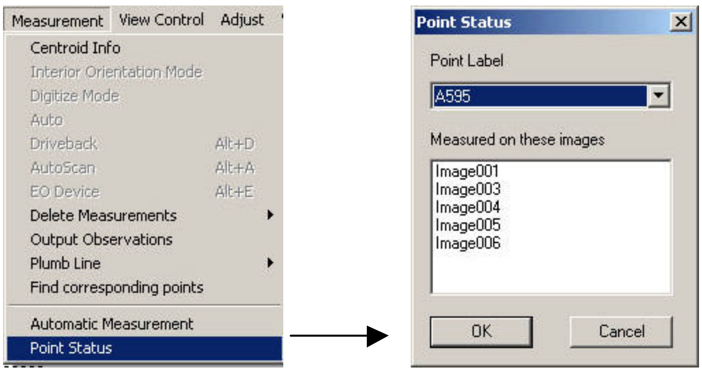


Figure 4.17: Point status summary

5. Photogrammetric Orientation Procedures

5.1 The Adjustment Control Variables Dialog

This dialog is displayed by selecting the **Adjustment Controls** item from the **Adjust** menu (Fig. 5.1). Control options for all adjustments (bundle, triangulation, resection, relative orientation) such as convergence limit, maximum iterations, and rejection limit (in micrometres) are modified here. Additionally, the default image coordinate sigma (in millimetres), minimum number of acceptable rays, and the rejection criteria *can* be modified if necessary. The rejection limit is fixed by checking the corresponding box. Total error propagation (rigorous variances) may be toggled on or off.

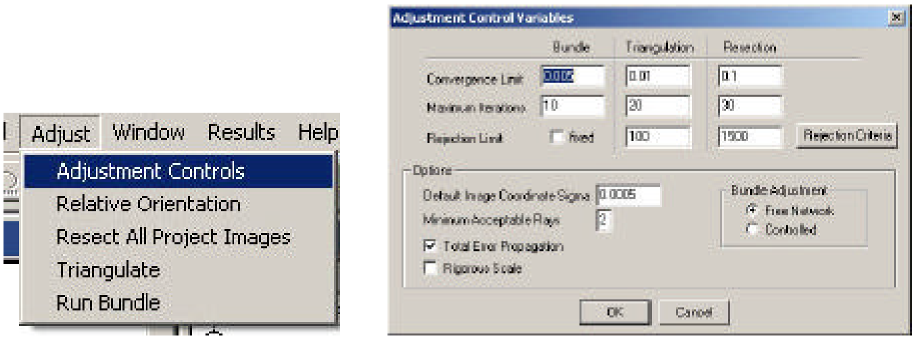
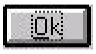


Figure 5.1: The adjustment controls dialog.

If one or more scale bars are present in the project, they will be utilised in the bundle adjustment. If the *Rigorous Scale* box in the **Adjustment Controls** dialog is not checked then scaling will be done post-bundle (the box will only appear when a scale bar is entered in the project). In this case, the scale factor is computed from the given and adjusted values of the scale bar length. If multiple scale bars are used, the scale factor is averaged. This scale factor is then applied to the adjusted 3D point and image station XYZ coordinates and their corresponding standard errors. Checking the *Rigorous Scale* box causes the given scale bar length to be used rigorously as an additional observation in the bundle adjustment. As mentioned in Section 2.2.1, if the scale bar is to be used rigorously in the bundle adjustment, the standard error of the bar length must be entered in the ***Scale Bar Database*** dialog.

Appropriate default values for all controls are shown in Fig. 5.1. These settings are sufficient in most situations. After making changes, select 

to close the dialog.

5.2 Resecting a Single Image

Assuming sufficient observations have been made (minimum of four well-distributed points) a resection may be performed in either the image or project views. This is accomplished by right clicking in the image itself or on the image icon and selecting **Resect This Image** from the resulting popup. This opens the **Resect Camera Station** dialog (Fig. 5.2).

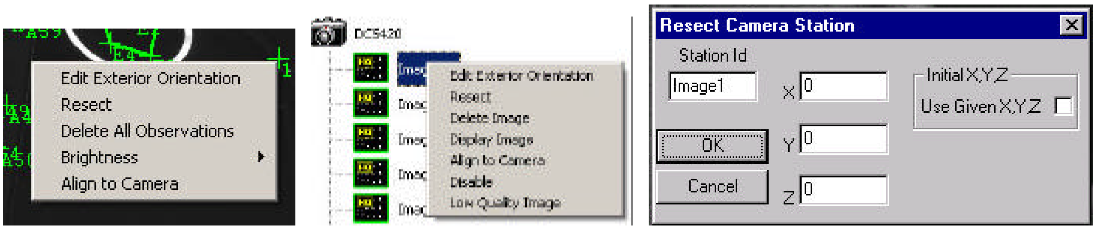


Figure 5.2: Resect a single image from the image view (left) or the project view (centre) via the Resect Camera Station dialog (right).

The user can provide initial image station coordinates for the resection by filling in the X, Y, and Z edit boxes in the **Resect Camera Station** dialog. Checking the **Use Given X,Y,Z** box ensures that these initial values will be utilised. Upon clicking the OK button the resection is performed. If the **Use Given X,Y,Z** box is not checked, automatic computation of initial station coordinates is attempted by *closed-form resection*. The closed-form solution is recommended. In the event that the closed-form fails to provide adequate initial values the user may then supply his/her own, checking the **Use Given X,Y,Z** box.

5.3 Resecting All Images in the Project

Prior to performing a bundle adjustment, all images in the project should be resected to provide optimum exterior orientation values. Select the **Resect All Project Images** item from the **Adjust** menu (Fig. 5.3). Resection results are summarised in the results dialog box. Any images that fail may be resected individually as described in Section 5.2.

Whenever the *Driveback* or *Control* file is changed it is necessary to select **Resect All Project Images** again prior to running a bundle adjustment. This will ensure coordinate system compatibility in the bundle adjustment between the preliminary XYZ coordinate datum and that of the control points.

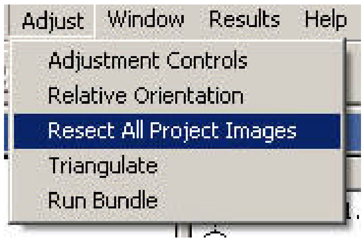


Figure 5.3: Adjust Commands - Resect all project images.

5.4 Performing the Bundle Adjustment

To perform the bundle adjustment, select **Run Bundle** from the **Adjust** menu or use the **Bundle** button on the toolbar. This displays the *Bundle Adjustment* dialog (Fig. 5.4). A summary of the number of images, points, control points, and scale bars appears in the Summary group. The *Adjustment Control Variables* dialog may be accessed with the **Adjustment Controls** (Fig. 5.1) button in the lower left corner.

If a 3D datum control file has been imported, the bundle may be run as either a free network or a controlled adjustment, depending upon which radio button is checked in the *Adjustment Control Variables* dialog. If no control file is present, only the free network option is available and “Free Net” appears in the Control Points box.

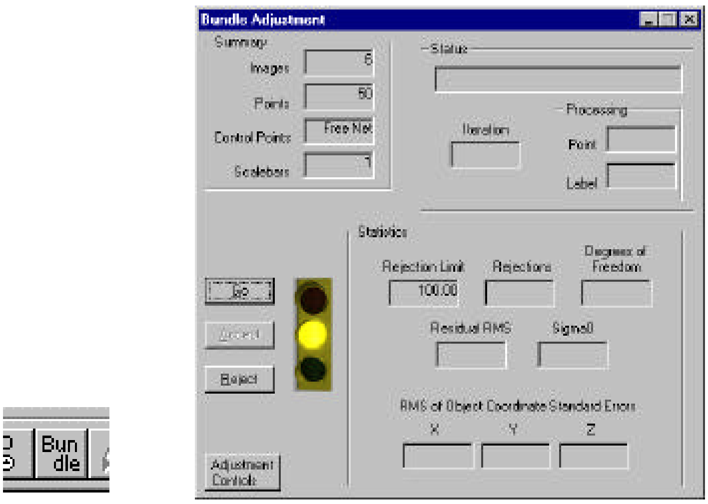


Figure 5.4: Running the bundle adjustment.

Images that have not been measured or successfully resected are automatically withheld from the bundle adjustment. An image is manually withheld by right clicking on its icon and selecting **Disable** from the floating menu (Fig. 3.2). The image icon changes accordingly.

To run the bundle, press the **Go** button. A message indicating success or failure appears in the Status group at the top right of the dialog. Additionally, the stoplight icon indicates green for success or red for failure. If the adjustment is successful, the **Accept** button is enabled. If the bundle is accepted, the database is modified with newly adjusted camera parameters. The *Bundle Adjustment* dialog closes and the resulting *xyz* file icon appears in the project tree with the name *Bundle*. The resulting Bundle.xyz file is automatically set as the current driver file.

5.5 Triangulation

In certain applications it may be necessary to triangulate imagery without first performing a bundle adjustment, or occasionally a resection. As an example, consider a work cell consisting of four cameras in fixed positions. A single point within the work cell volume can be triangulated if all camera exterior orientations are known. Triangulation is accessed from the **Adjust Menu** (Fig. 5.1).

Triangulation of two or more images (with or without bundle adjustment/resection) can be accomplished within *Australis* by either first manually setting the exterior orientation (EO) parameters of the two or more images, or by using previously resected images. To enter EO parameters, right click an image icon in the project view and select **Edit Exterior Orientation** from the popup menu (Fig. 3.2). This popup menu is also accessible within the image view by right clicking anywhere within the image. The *Edit Camera Station* dialog is then displayed, where the exterior orientation parameters can be entered (Fig. 5.5). To permit triangulation with this image without rigorously resecting, the *Accept as Resected* box at the lower right of the dialog must be checked.

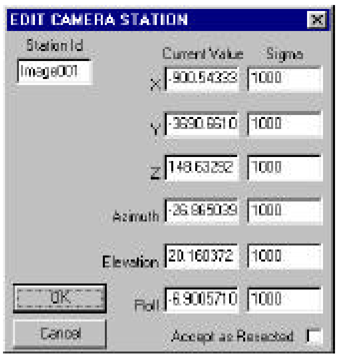


Figure 5.5: Edit Camera Station dialog.

To perform the actual triangulation, select **Triangulation** from the **Adjust** main menu item. This displays the *Triangulate* dialog box (Fig 5.6). Images displayed in the list box are only those that have been accepted as resected as mentioned above and have at least one observation. Within the list box, images can be enabled or disabled for triangulation by right clicking and choosing either Enable or Disable from the resulting popup menu. Disabled images are highlighted in red (Fig 5.6). Triangulation is performed by choosing the *Triangulate* button. Upon completion, the total RMS of the image coordinate residuals is displayed. If the results are accepted, The *Triangulate* dialog closes and the resulting *xyz* file icon appears in the project tree with the name *Triangulate.*

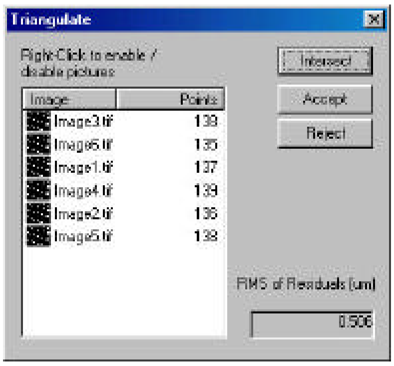


Figure 5.6: Triangulate dialog.

5.6 Relative Orientation

The **Relative Orientation** (RO) capability incorporated into *Australis* has one primary purpose: to establish preliminary XYZ object point coordinates of a subset of 6 or more object points seen in two images such that these can be used to support subsequent resection and resection driveback. Thus, the user can start the survey with NO preliminary object space knowledge; neither an EO device nor preliminary approximate coordinates of 4 or more points are required. The RO would thus be performed only once and involve only two images (any two which are suitable). After RO, the process reverts to the standard resection driveback sequence familiar to Australis users. This section gives a brief guide to running the RO, the graphic presentation of which appears in Fig. 5.7. In order to initiate RO, select the Adjust menu and then Relative Orientation. A more complete account of the Relative Orientation Procedure is provided in Tutorial 4 of Chapter 10.

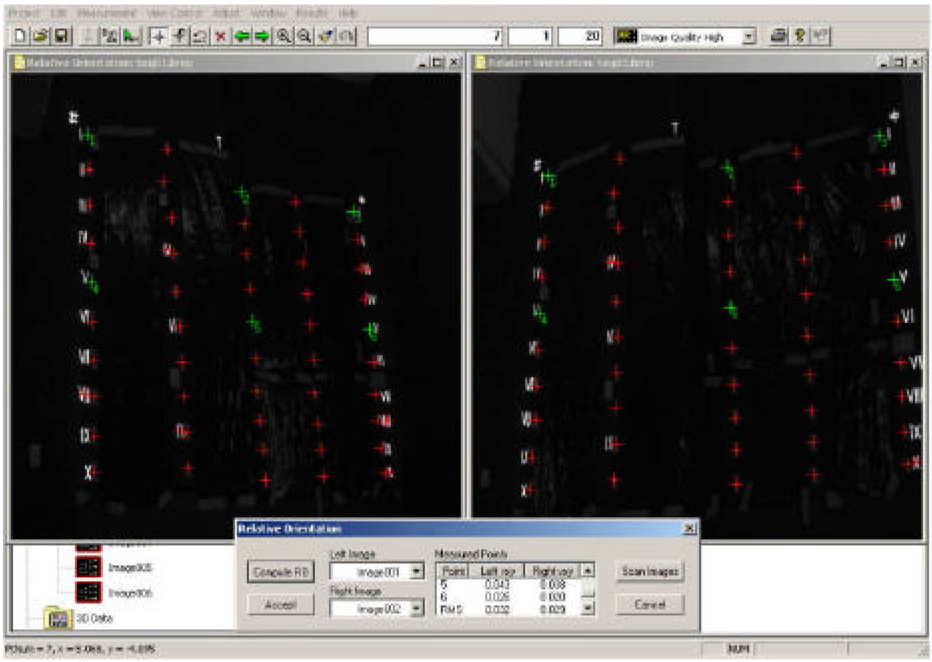


Figure 5.7: Relative Orientation dialog.

5.7 Output Files

Single output results summary files are produced by the resection, triangulation and 3D coordinate transformation commands. The bundle adjustment itself produces up to five files. The files created are shown in Figure 5.8. The bundle adjustment always generates a 3D coordinate file and standard bundle adjustment output file. Dependent upon the project preferences, additional files include image coordinate residuals, adjusted camera parameters, and correlation matrix data.

Output filenames *may*, by default, be prefaced with the name of the current project. All extensions are *txt*. The files are written by default to the current project directory. Eg, the following files can be generated:

Resection.txt
Triangulation.txt
Bundle.txt
Residuals.txt
Camera.txt
Correlation.txt
Trans.txt

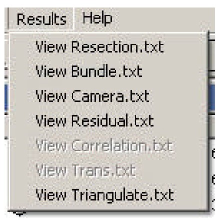


Figure 5.8: Output files.

Sample output files are found in Appendix A. Output files are viewed within *Australis* using the commands in the **Results** menu (Fig. 5.8). The files are displayed in the Windows *Notepad* editor. The *Bundle.XYZ* object coordinate file and other 3D data files can also be output in DXF format.

6. Automatic Operation

Through the combination of a number of features of *Australis* it has been possible to implement fully automatic orientation/triangulation and self-calibration of a close range potogrammetric network.

Prerequisites for this are firstly an *Australis*-compatible EO device (Sect.3.2.5 and 4.13) and secondly the requirement that all images in the network include the EO device along with well-defined, high contrast targets. The aim in providing this feature is not so much to accommodate any and all network configurations, but more to indicate the utility of full automation, especially for convenient digital camera calibration.

The full Automation steps, taken separately, include:

1. **AutoScan of all Images** – the outcome of which is measured, unlabelled image points as well as preliminary exterior orientation (see Sect. 4.3 and Sect. 4.13).

2. **Find Corresponding Points** – the outcome of which is a full set of labelled image points (Sect 4.15).

3. **Fast Bundle Adjustment** – the outcome of which is a refined, but still not final network orientation (as per Chapter 5).

4. **Postprocessing** – the outcome of which is a refined image point correspondence determination, as well as preparation of the network for final bundle adjustment.

5. **Final Bundle Adjustment** – the outcome of which are the final adjusted object space coordinates and sensor calibration data (as per Chapter 5).

At present the operator need only step through these operations sequentially, or select the single **Automatic Measurement** option. The latter is initiated via either the *AM* button (green arrowhead) on the toolbar or through the pull-down **Measurement** menu, as indicated in Fig. 6.1.

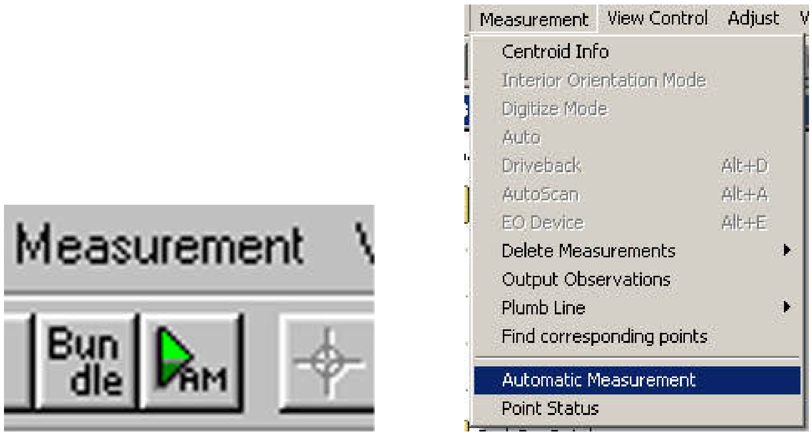


Figure 6.1: Initiating Automatic Measurement.

The dialog shown in Fig. 6.2 appears when automatic measurement is selected. It is possible via the options in this dialog box to run only certain phases of the automation process, and it is also possible to set *project preferences* as per the standard preference options for *image scanning* and *finding corresponding points* (Sect. 3.5) and for *adjustment controls* (Sect. 5.1).

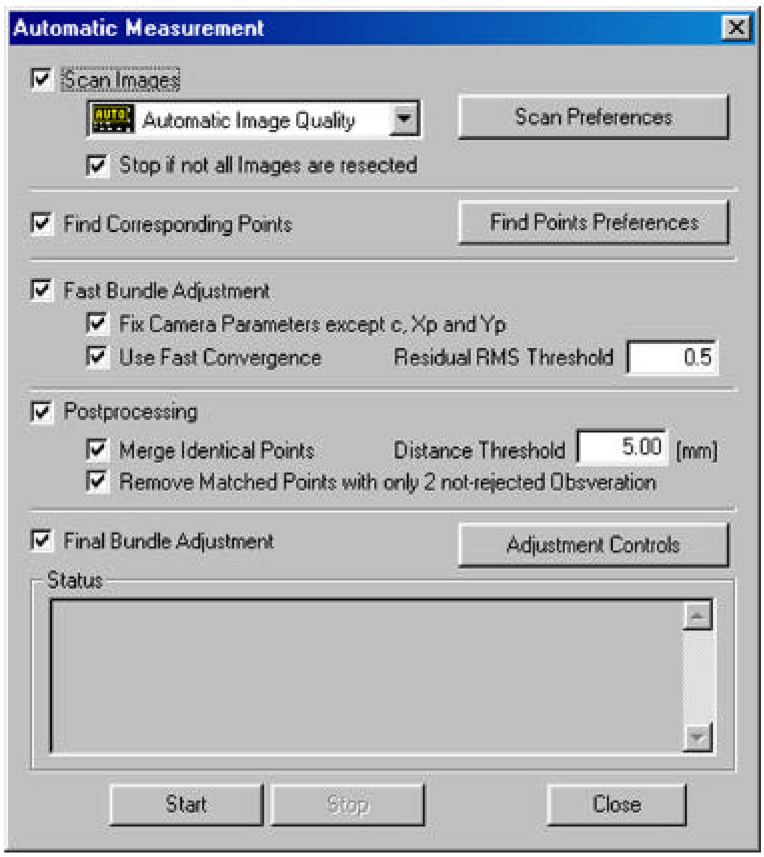


Figure 6.2: Dialog box for automatic measurement.

Once the automatic measurement commences, the status of the process is indicated as illustrated in Fig. 6.3 and successful completion is indicated by normal termination of the bundle adjustment, Fig. 6.4.

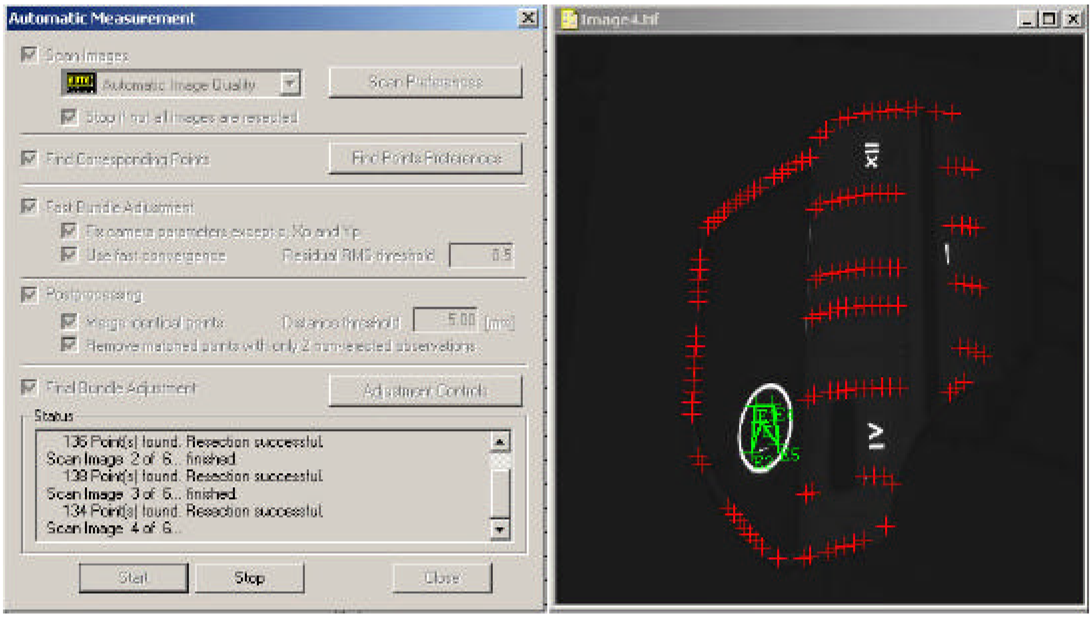


Figure 6.3: Status of automatic measurement.

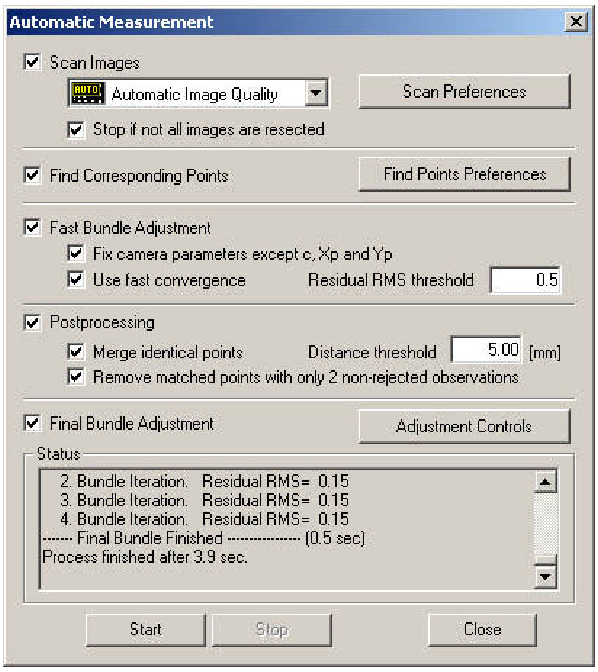


Figure 6.4: Completion of automatic measurement.

7. 3D Graphic View

The 3D Graphic View serves primarily as a simple visualisation tool (Fig. 1.3). Any imported 3D coordinates may be displayed. For point clouds generated by the bundle adjustment, sensor stations and scale bars may be displayed as well. Indeed, resected camera station positions may be displayed in conjunction with any set array of object points. It is therefore important that the XYZ coordinate system of the camera stations be consistent with that of the object points if both are to be displayed together. For point clouds generated by 3D transformation (Chapter 9), discrepancy vectors may be displayed (Section 7.3). When an EO device (*.eod) file is displayed, the lines joining the EO points are also plotted.

Additionally, a number of analysis routines are available. These include point-to-point distance and best-fit lines, planes, and spheres. (**DISCLAIMER**: Although provided with *Australis*, best-fit functionality is yet to be fully verified through comprehensive testing and is thus not fully supported at present)

The 3D view is displayed by double clicking a 3D data file icon in the project tree or by right clicking the icon and selecting **Graphic View** (Fig. 7.1).

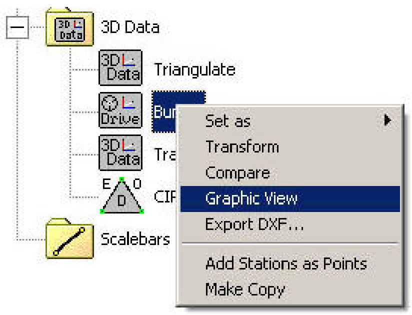


Figure 7.1: Displaying the 3D graphic view.

7.1 Display Controls

Positioning of the graphic elements within the view is done primarily by moving the mouse with the right button down.

7.1.1 Rotation

Moving the mouse horizontally across the view window with the right button down rotates the cloud about a line parallel to its Y-axis. Similarly, moving the mouse vertically rotates the cloud about a line parallel to its X-axis.

7.1.2 Translation

Translate the cloud within the window by moving the mouse with the right button down while simultaneously pressing the SHIFT key.

7.1.3 Zooming

Zooming is performed with the up and down arrow keys ($\uparrow \downarrow$). The up and down arrows zoom out and in respectively. If using a Microsoft IntelliMouse, the wheel button also provides zooming functionality. Rolling the wheel towards the user zooms in while rolling away zooms out.

7.1.4 Changing Coordinate Axes Size

The size of the displayed coordinate axes can be changed using the left and right braces keys $\left\{ \begin{matrix} \{ \\ [\end{matrix} \text{ and } \begin{matrix} \} \\ ] \end{matrix} \right\}$. The key "}" increases the size while "{" decreases the size.

7.1.5 Changing Point Intensity

For greater visibility, the intensity of displayed points can be changed using the *greater than* and *less than* keys $\left\{ \begin{matrix} < \\ , \end{matrix} \text{ and } \begin{matrix} > \\ . \end{matrix} \right\}$. The key ">" increases the point intensity while "<" decreases intensity.

7.1.6 Feature Identification

Points, sensor stations, and scale bars can be identified in the graphic view by resting the cursor over the feature of interest. A popup window gives the feature description (Fig. 7.2). Points and camera stations are identified by both their label and 3D coordinates.

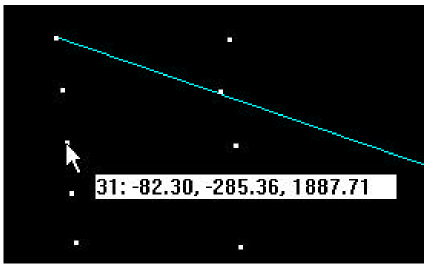


Figure 7.2: Feature identification in the graphic display.

7.1.7 Displaying Camera Stations and Scale Bars

Resected camera stations can be shown with any set of 3D object point coordinates, whereas scale bars can be displayed only for point clouds generated by the bundle adjustment. To display either, right click in the view window and select **View Camera Stations** and/or **View Scale bars** in the resulting popup menu. Repeat to toggle off the display.

Note also that camera station positions can be added s additional object points to the **Bundle file.** As per Fig. 7.1, simply select **Add Stations as Points** in the pull-down menu and the camera stations will be added in the graphics display as additional object points.

7.1.8 Varying Size of Displayed Camera Station Icons

To vary the size of the displayed camera station icons (a camera), use the “1” key on the keyboard to reduce the size and the “2” key to increase the displayed size.

7.1.9 Selecting Points

Points must be selected in the view window in order to perform the analysis functions described in Section 7.3. This is accomplished with the left mouse button alone or in combination with the SHIFT key.

To select a single point, either press the SHIFT key and click on the point with the left mouse button, or with the left mouse button pressed, drag the selection box (Fig. 7.3) over the point. More points can be added to the selection in the same manner. To unselect all points, release the SHIFT key and click anywhere in the view with the left mouse button.

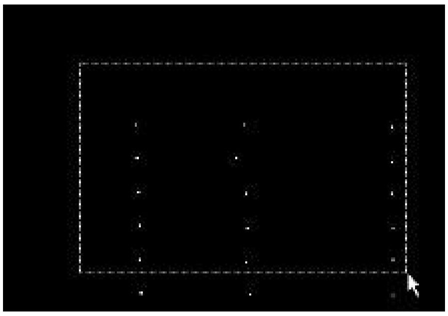


Figure 7.3: Multiple point selection by dragging with left mouse button.

To select multiple points, hold the left mouse button down and drag the displayed rectangle around the points (Fig. 7.3). New points are added to the selection by holding down the SHIFT key and dragging around or by selecting single points as described above.

7.2 Displaying Imaging Rays

It is possible to indicate the imaging rays to any object point within a 3D graphics display of points and camera stations. Measured rays to a single or multiple points can be displayed, as is indicated in the examples shown in Fig. 7.4. To display imaging rays, simply highlight the point or points for which imaging rays are requested and then select the ‘R’ key on the keyboard (you might ned to slightly move the mouse to the action to occur). To turn the ray display off, simply hit ‘R’ a second time. The ‘R’ key toggles the display on and off.

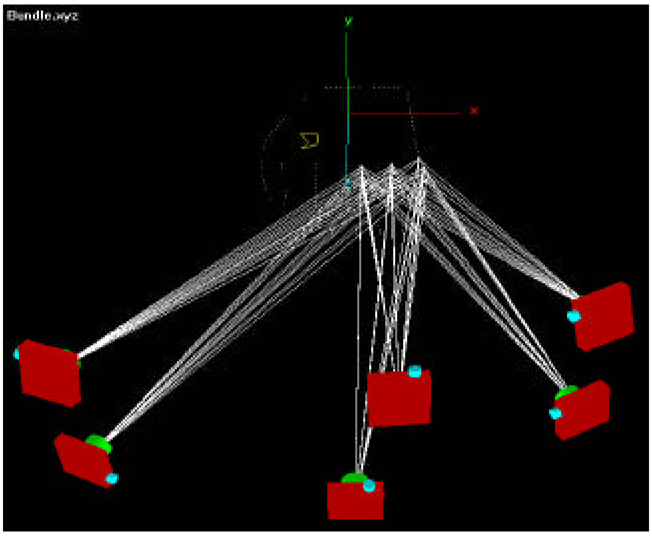


Figure 7.4: Displaying Imaging Rays via point highlighting and the 'R' key.

7.3 Analysis Functions

Results for all best-fit functions are displayed in popup dialog boxes and written to files in the project directory. No graphical display of the results is provided at the time of writing. These files are overwritten every time the functions are performed.

7.3.1 Point-to-Point Distance

This function is available only when two points are selected in the view. Similar to the functionality described in Section 3.6 for the project list view, right click in the view window and select DISTANCE as shown in Fig. 7.5. The distance between the points is given in a popup dialog box, but it is **not** saved to a file.

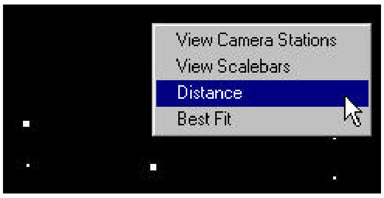


Figure 7.5: Computing point-to-point distance.

7.3.2 Best-Fit Line

Two or more points must be selected to compute a best-fit line in space. Right click in the view window and select BEST FIT | LINE. Parameters of the best-fit line through these points are computed by least-squares adjustment. These include the components of the lines unit directional vector and a point on the line. Final parameters and residuals are displayed in a popup dialog box (Fig. 7.6) and written to the file BestFitLine.txt in the project directory.

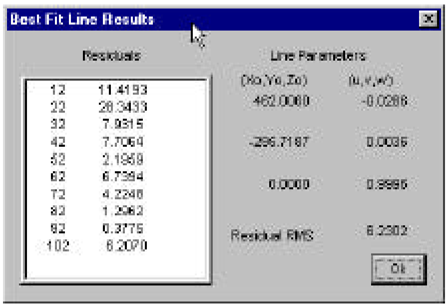


Figure 7.6: Best fit line results.

7.3.3 Best-Fit Plane

A minimum of three points must be selected to compute a best-fit plane. Right click in the view window and select BEST FIT | PLANE. Plane parameters are computed by least-squares adjustment. Final parameters and residuals are displayed in a popup dialog box similar to Fig. 7.6 and written to the file BestFitPlane.txt.

7.3.4 Best-Fit Circle

A minimum of 4 points must be selected to compute a best-fit circle. Right click in the view window and select BEST FIT | CIRCLE. Circle parameters are computed by least-squares adjustment. Final values and residuals are displayed in a popup dialog box similar to Fig. 7.6 and also in BestFitCircle.txt in the project directory.

7.3.5 Best-Fit Sphere

A minimum of four points must be selected to compute a best-fit sphere. Right click in the view window and select BEST FIT | SPHERE. Sphere parameters are computed by least-squares adjustment. Final parameters and residuals are displayed in a popup dialog box similar to Fig. 7.6 and written to the file BestFitSphere.txt in the project directory.

7.4 Viewing Coordinate Data from 3D Transformation

With the *Trans.xyz* file displayed in the 3D graphic view, right click to display the popup menu and select **View Discrepancy Vectors** (**Ctrl + V**). An initial display scale factor is determined to ensure that the vectors are visible on screen. The current display scale is seen at the bottom left of the screen. The scale may be changed via the "PgUp" and "PgDn" keys. Placing the mouse cursor over a vector displays a popup window with the point label and corresponding vector length. This is illustrated in Fig. 7.7. These vectors represent the change in shape, as expressed by relative point movements between the two files used in the 3D coordinate transformation.

Figure 7.7: Display of discrepancy vectors from Trans.xyz file.

8. Interior Orientation

As mentioned in Section 2.1, *Australis* supports the capability to re-establish the interior orientation of scanned metric images with fiducial marks and/or reseau points. This chapter describes the procedure. Section 10.5 provides a tutorial with two sample images.

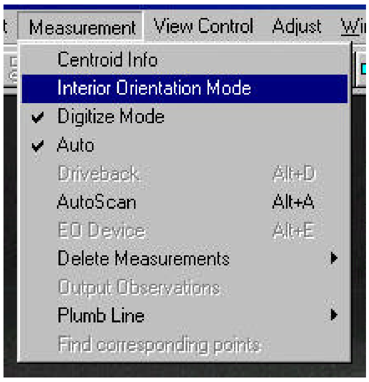


Figure 8.1: Invoking IO Mode.

8.1 Importing Fiducials

The import of fiducial points and the format for a fiducial coordinate file is given in Section 2.1.2.

8.2 Measuring Fiducials in IO Mode

With the desired camera in the active project, open an image as described in Section 4.1. Measurement of fiducial and reseau points may be accomplished manually or with automatic centroiding, depending on the type of point. To place *Australis* in Interior Orientation mode, select the **MEASUREMENT | INTERIOR ORIENTATION MODE** menu item as shown in Fig. 8.1.

This opens the Interior Orientation Results dialog (Fig. 8.2). Calibrated fiducial coordinates will appear in the dialog. In switching to IO mode, the cursor is automatically set to **ZOOM**. All *point delete* functionality operates in the same manner as in the measurement of standard image coordinates.

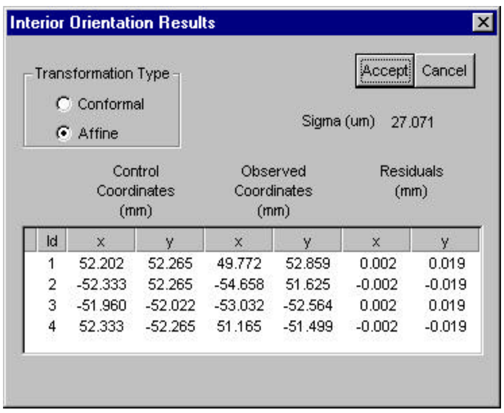


Figure 8.2: Interior orientation results dialog.

The measurement proceeds as follows. Zoom in on the first point, switch to digitise mode and measure it. Within two seconds the image is automatically refreshed to full screen resolution and the cursor is reset to ZOOM. Remaining fiducials are measured in the same manner. The Interior Orientation Results dialog remains visible throughout the interior orientation procedure. It will be necessary to drag it out of the way in the event that it obscures a point to be measured.

As fiducials are measured, the coordinates appear in the Interior Orientation Results dialog. Affine and conformal 2D transformations are available. These are toggled using the Transformation Type radio buttons. Once the minimum number of measurements have been made for the active transformation, the transformation parameters are determined by a least squares adjustment (3 for conformal and 4 for affine). The measurement residuals and current sigma are displayed as in Fig. 8.2).

When an acceptable interior orientation has been attained, select the **Accept** button in the upper right of the Interior Orientation Results dialog. The user is prompted to confirm that the resulting transformation parameters will be applied to all subsequent measurements (Fig. 8.3). Upon acceptance, the Interior Orientation Results dialog is closed and the transformation parameters are saved.

Figure 8.3: Interior orientation confirmation notice.

The remainder of the image is measured normally. The interior orientation can however be modified at anytime by once again entering Interior Orientation mode and measuring additional points or editing the existing measurements.

Attempting image measurement before performing the interior orientation produces a warning dialog.

9. 3D Transformation and Setting of Object Coordinate System

9.1 3D coordinate Transformation

A three-dimensional transformation of a point coordinate file is accomplished from the project tree. Right click on the icon of the file to be transformed and choose **Transform** from the popup menu (Fig. 9.1). From the displayed **File Open** dialog, double click the control file for the transformation. This displays the 3D Transformation dialog (Fig. 9.2). When this dialog box opens, the control and secondary files are displayed along with the number of common points between them (based on label). The file of transformed coordinates is always named *Trans.xyz* and is written to the project directory. This file will be overwritten with subsequent transformations.

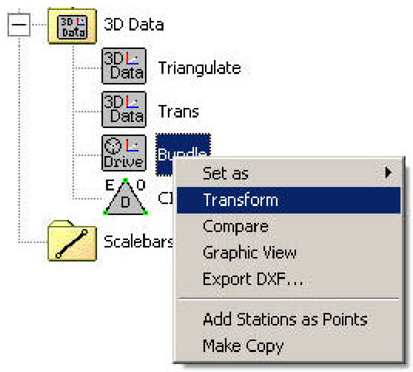


Figure 9.1: Starting 3D transformation.

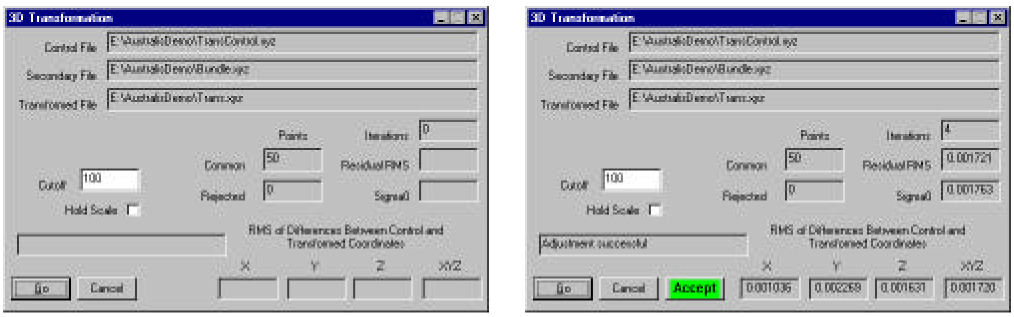


Figure 9.2: 3D transformation dialog (left). With Accept button highlighted (right).

The rejection cutoff can be changed. If necessary, the scale of the secondary file can be held fixed by checking the **Hold Scale** box. Clicking the **Go** button performs the transformation. If the adjustment is successful, the **Accept** button is displayed and an appropriate message is displayed in the box above.

Results displayed in the dialog include the number of iterations and rejected points, the residual RMS value, and the mean error of unit weight. The RMS value of differences between control and transformed coordinates is also displayed.

Upon acceptance, the results of the transformation are written in the project directory to the file *xxx*_Trans3D.txt where *xxx* is the project name. This file is also overwritten with subsequent transformations. An icon for the transformed coordinates appears under the project 3D Data Files icon. These coordinates can be viewed graphically as described in Chapter 7, Section 7.3.

9.2 Setting Object Point Coordinate Axes

Within *Australis,* there are number of object point coordinate system orientations that may be adopted. For example, in Relative Orientation the origin and orientation of the XYZ system are defined via the 'left' camera station position. In a resection operation, the network XYZ system is established by the coordinate system of the driveback points. Also, within a free-net bundle adjustment, the coordinate system is implicitly set, though it can be expected to be close to that of the driveback points or the initial RO'd points. Also, we have just seen that it is possible to utilise a 3D transformation to establish a desired XYZ reference coordinate system.

Another possibility is to interactively set the desired origin and orientation of the reference coordinate system using the so-called 3-2-1 approach. Here, three points are highlighted within the 3D graphics display of the object point file concerned. The XYZ coordinate system is then assigned as follows:

1) The first highlighted point defines the new origin (0,0,0)

2) The second highlighted point defines the direction of the positive X-axis, ie the X-axis will run from the origin through this point.

3) The third highlighted point, along with the first two, defines the spatial orientation of the XY plane, ie the established XY plane will contain all three points, with the positive Y-axis being 'towards' the third point.

4) The positive Z-coordinate axis is then set to be normal to this plane, with its direction such that right-handedness of the coordinate system will be maintained.

The scale of the coordinates is retained throughout this process.

To initiate the 3-2-1 coordinate axes assignment, first select (highlight using the SHIFT key) the three points, paying attention to the order in which they are highlighted (the actual point selection operation is described in Section 7.1.9), and then right-click in the 3D graphic view window and select ***3-2-1***, as indicated in Figure 9.3. Alternatively, if you wish to define the axes by point labels, select ***3-2-1*** without highlighting any points and the menu box shown in Fig. 9.4b will appear. You then simply add the point labels, noting that you can also change the direction of axes by ticking the appropriate orientation choices.

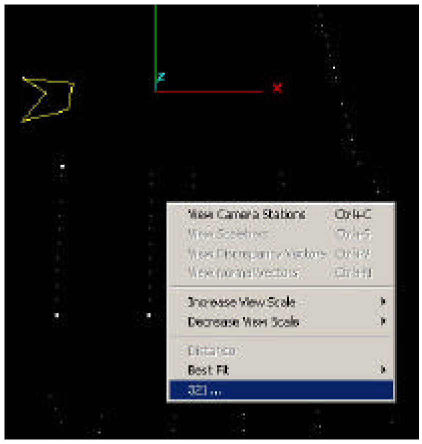
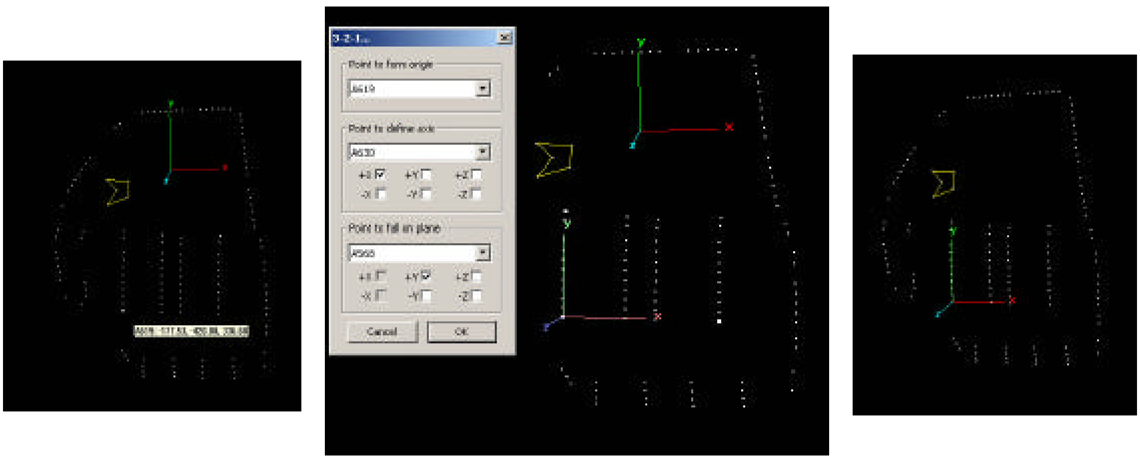


Figure 9.3: 3-2-1 axes setting.

Shown in Fig. 9.4 is the sequence of establishing the coordinate axes via this approach. Fig. 9.4a shows the first highlighted point selected. Fig. 9.4b shows all three points selected and Fig. 9.4c shows the final axes for the assigned XYZ system.



(a) (b) (c)

Figure 9.4: Stages of setting an XYZ axis alignment.

Note: It is important to note that if the coordinate system of the 'Driver' file (especially the **bundle** file) is changed at any time via the 3-2-1 process, then all images will be changed into the new coordinate system. But, if the file is a non-driver file then the camera station coordinates will not be changed. When setting another 3D data file as the driver it will be important that the operator first selects **Resect all Project Images** to bring the camera station positions and orientation into alignment with the new coordinate system of the 3D data file. The re-resection must occur before subsequent operations such as further bundle adjustment or spatial intersection (triangulation).

10. Tutorials

10.1 Tutorial 1: Semi-Automatic Image Measurement

(AUSTRALIS DEMO 1)

This chapter gives step by step instructions for the measurement and adjustment of the image files provided with the *Australis* Demonstration Projects. Instructions are provided both for measuring images directly and for the adjustment of imported image coordinate data. This first section is for 'normal' semi-automatic measurement (no EO device) of the object point array shown in the following figure. It is assumed that some or all points have approximately known XYZ coordinates.

This is called *Demo 1*. It is assumed that the files provided have been installed as follows:

$:\AustralisDemo\Demo1\ Object.xyz

$:\ AustralisDemo\Demo1\Seq01.bmp
Seq05.bmp
Seq11.bmp
Seq30.bmp
Seq31.bmp
Seq45.bmp

$:\ AustralisDemo\Demo1\ImageCoordinateFiles\Seq01.icf
Seq05.icf
Seq11.icf
Seq30.icf
Seq31.icf
Seq45.icf

Sequence:

1. Start *Australis*. Select FILE|NEW to start a new project.
2. Select the object space units, in this case millimetres (this is important for correct scaling of the graphics output – it does not effect the photogrammetric triangulation)
3. Drag and drop camera ***BMP-DemoCam*** from the ***Camera Database*** to the project.
4. Drag and drop the scale bar ***DemoBar*** from the ***Scale bar Database*** to the project ***Demo*. ** Note that there is not an actual scale bar present in this imagery. ***DemoBar*** is simulated with the distance between two known points.
5. Right click on the ***BMP-DemoCam*** camera icon in the Demo1 project and select ***Set Image File Directory***. This displays the *Select Image File Directory* dialog. Set the directory to $:\AustralisDemo\Demo1 and press Open. All images are added to the project.
6. Save the project as ***c:\AustralisDemo\Demo1\Demo1.aus*** using either the FILE|SAVE AS menu item or the floppy disk button on the tool bar.
7. Right click on the 3D Data icon and select IMPORT | DRIVEBACK FILE. Select the file ***Object.xyz*** from the ***c:\AustralisDemo\Demo1*** directory.
8. Open Image001 by double clicking on its icon. Measure points 11, 15, 101, and 105 using the image point map provided in the figure above.
9. From the ***Measurement*** menu item select ***Driveback***, or press the driveback button on the toolbar, or use the key combination ALT+D. A resection is performed. Accept upon convergence. The remainder of the points in the image will be measured automatically.
10. After measurement is complete, proceed to the next image via the blue arrows on the Toolbar, or first close the image by double clicking on the camera icon in the upper left of the image window or single clicking on the **x** button in the upper right of the image window.
11. Repeat steps 7 - 9 for all remaining images (use of the blue arrows automatically opens the next or last image). Also, if Points 15 & 105 are not imaged, use alternatives such as 15 and 102.
12. After all images have been measured, from the ***Adjust*** menu item select ***Resect all Project Images***. Resections will be performed for all images using all measured points.

13. Check the **Parameter Correlations** checkbox in the Project Preferences Output dialog.

14. Run the bundle adjustment by selecting ***Run Bundle*** from the ***Adjust*** menu item or by clicking the ***Bundle*** button on the toolbar. **Accept** upon convergence (you must **Accept** to get Results files & an updated *Bundle.xyz* file).

15. The output files from the adjustment may be examined by selecting from the ***Results*** menu: ***Resection.txt***, ***Bundle.txt***, ***Camera.txt***, ***Residual.txt & Correlation.txt.*** (example copies are provided in the directory *AustralisDemo\Demo2\Results*).

16. View the network by double clicking on the Bundle file under the 3D DATA icon. Perform any object point analysis required.

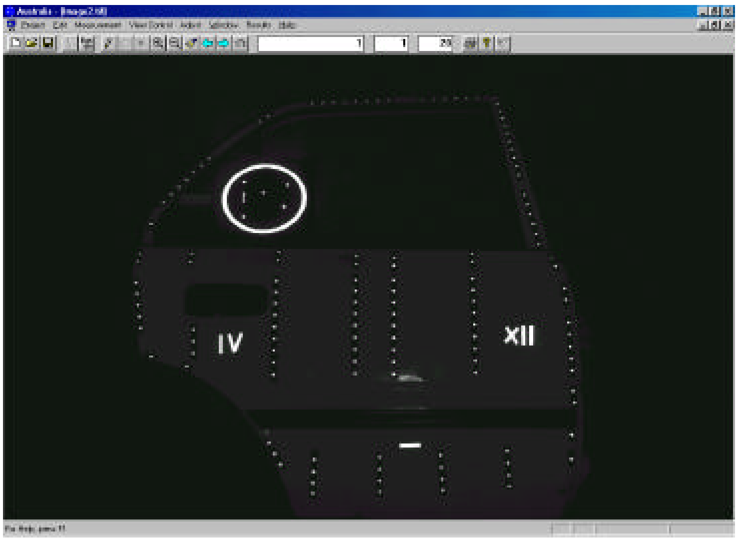
17. Save the project and exit.

10.2 Tutorial 2: Automatic Measurement with an EO Device

(AUSTRALIS DEMO 2)

This section gives step by step instructions for the automatic measurement (via autoscanning and an EO device) for the car-door network (object shown below) provided with the *Australis Demo Project* for *Demo 2*. It is assumed that the files provided have been installed as follows:

$:\ AustralisDemo\Demo2\Image1.tif
Image2.tif
Image3.tif
Image4.tif
Image5.tif
Image6.tif
$:\ AustralisDemo\Demo2\Circle.eod



Sequence:

1. Start *Australis*. Select FILE|NEW to start a new project.

2. Select the object space units, in this case millimetres (this is important for correct scaling of the graphics output – it does not effect the photogrammetric triangulation)

3. Drag and drop camera ***DCS420*** from the ***Camera Database*** to the project.

4. Right click on the ***DCS420*** camera icon in the Demo project and select ***Set Image File Directory***. This displays the *Select Image File Directory* dialog. Set the directory to $:\AustralisDemo\Demo2 and press Open. All images are added to the project.

5. Save the project as ***c:\AustralisDemo\Demo2\Demo2.aus*** using either the FILE|SAVEAS menu item or the floppy disk button on the tool bar.

6. Right click on the 3D Data icon and select IMPORT | EO DEVICE. Select the file ***Circle.eod*** from ***c:\AustralisDemo\Demo2***

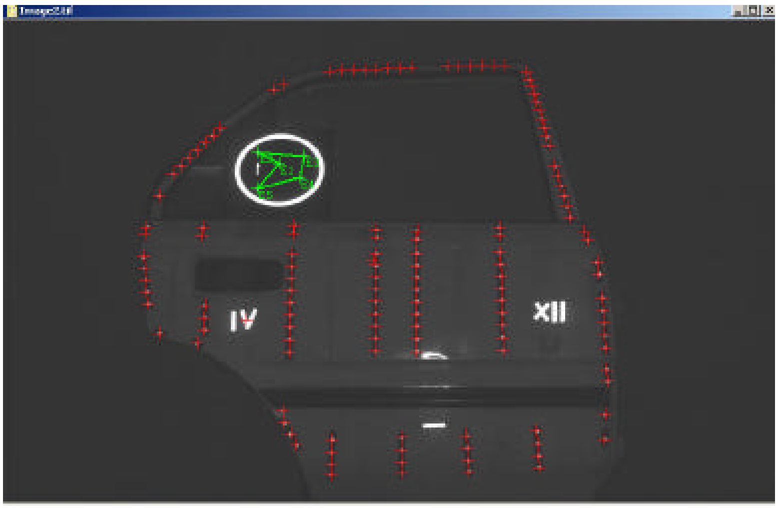
Then either choose a one-step solution:

7. Select ***AM*** from the toolbar or **Automatic Measurement** from the Measurement Menu (then go to Step 11 below).

Or process the automatic measurement in stages:

7. Right click on the project camera icon and select **AutoScan All Images**. Press OK if asked if previous measurements should be deleted and then press START SCAN. Close the dialog box after the AutoScanning is complete.

8. Open Image1 by double clicking on its icon. Confirm that the EO device has been measured and the points have also been detected and measured, as indicated by red crosses. Repeat this for each image, if you wish. You can step quickly through the images by using the blue forward and reverse arrows in the toolbar. An autoscanned image appears as indicated below:



9. Select FIND CORRESPONDING POINTS from the MEASUREMENTS menu and press START MATCHING. Confirm that the image point correspondence determination has been successful and close the dialog box.

10. Run the bundle adjustment by selecting ***Run Bundle*** from the ***Adjust*** menu item or by clicking the ***Bundle*** button on the toolbar. **Accept** upon convergence (you must **Accept** to get Results files & the *Bundle.xyz* file).

11. The output files from the adjustment may be examined by selecting from the ***Results*** menu item:

View Bundle.txt
View Camera.txt
View Residual.txt

12. View the network by double clicking on the Bundle file under the 3D DATA icon. Perform any object point analysis required.

13. Save the project and exit.

10.3 Tutorial 3: Bundle Adjustment with Imported Image Coordinate Data

1. Perform steps 1 - 5 from Section 10.1.

2. Right click on the ***DCS420*** camera icon in the Demo project and select ***Set Image Coordinate File Directory***. Then, set the directory to $:\AustralisDemo\Demo1\ImageCoordinateFiles and press ok. All coordinate files are added to the project.

3. After importing all image coordinate files and the driveback file, select ***Resect all Project Images*** from the ***Adjust*** menu item. All images will be resected.

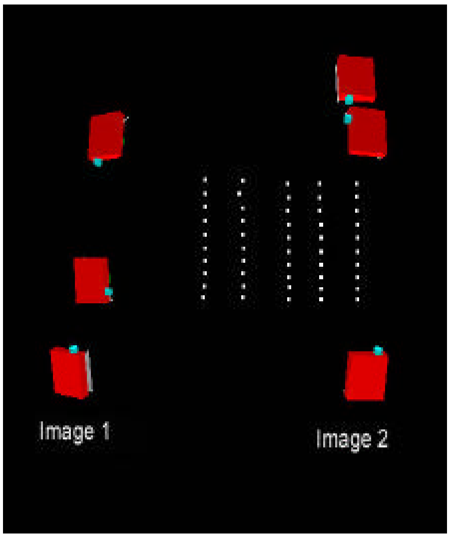
4. Run the bundle adjustment by selecting ***Run Bundle*** from the ***Adjust*** menu item or by clicking the ***Bundle*** button on the toolbar. Accept upon convergence.

5. The output files from the adjustment are as in Section 10.1.

10.4 Tutorial 4: Relative Orientation Procedure

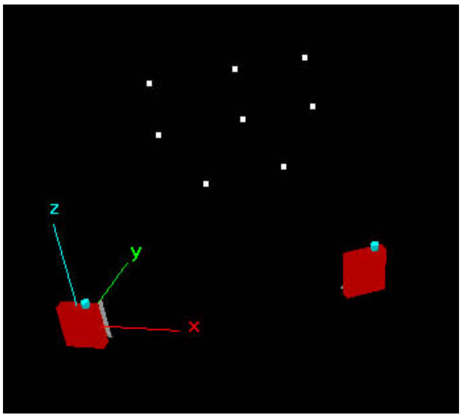
The RO Process

Imagine that it is desired to measure the XYZ coordinates (assume arbitrary origin, orientation and scale at this point) of the object points indicated in the figure below, using 6 images recorded from the camera station positions shown. Beyond certain camera calibration information, there is no knowledge of any positional information, related to either the object points or the camera stations.



With previous versions of *Australis*, one could not proceed without some initial estimates of object point position, via either an EO device or by estimating XYZ coordinates of 4 or more points (again in an arbitrary coordinate system). With the relative orientation (RO) capability, this preliminary information is no longer required since it is possible to recover through *relative orientation* the 3D shape of a configuration of any two images and a subset of the object points (5 is the theoretical minimum for this, though *Australis* requires 6 'conjugate points').

We now advance a little and display what such a configuration might look like for the initially RO'd network above, remembering that only two images will be involved & there'll be a subset of, say, 6-10 points. Note in the figure that XYZ coordinates for the 8 points have been determined within a coordinate system with its origin at the 'left' camera station (the scale is set such that the separation of images is a given, arbitrary value). In the *Australis* context, what we have is an initial set of object point coordinates which can then be used for subsequent resection and resection driveback as the remaining images are measured sequentially in the normal fashion. Thus, the RO process basically starts and stops with the initial orientation of the first two images.



Before describing the operation of the RO, consider the full orientation scenario for the 6-photo network. This is listed as follows, with the steps in italics being those appropriate for networks where fully automatic target detection (image scanning) is applicable:

1. Select the two images to be relatively oriented; a reasonable geometry is anticipated in this choice.

2. *Autoscan the two images to qualify all artificial targets; they are simply identified as targets at this point.*

3. Carry out an RO for the two images, choosing a subset of 6-10 well distributed points, which will then become resection 'control' points.

4. *Perform an image point correspondence determination (Measurement/Find Corresponding Points) to find matching points and to label them (the RO points will not be re-labelled, of course).*

5. *Perform an initial triangulation to get the preliminary XYZ coordinates of all matched points. At this stage most or all of the points within the RO'd pair will have XYZ values & so they will also become points to support resection and resection driveback*.

6. Proceeding an image at a time, measure all remaining images, as usual with *Australis*, using the RO'd points as resection control *(and other points can be used as resection driveback points)*.

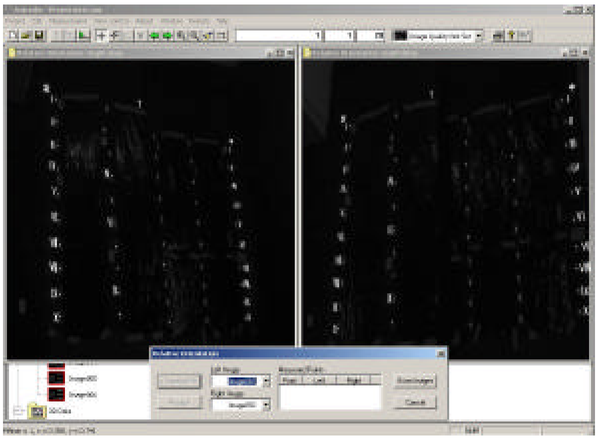
7. A bundle adjustment can be performed whenever desired within this sequence, though one should not of course consider self-calibration until there are sufficient images and a favourable imaging geometry (convergence & orthogonal roll angles).

8. After the final bundle adjustment of the full network, the XYZ coordinates can be scaled as usual via a scale bar, or transformed into a desired coordinate system via a 3D transformation.

Sequence of relative orientation operations with Australis for the test network shown above

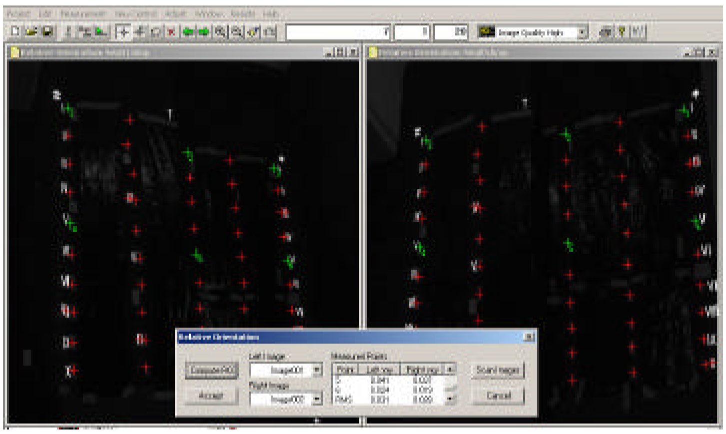
1. This network corresponds to that in *Australis* Demo1. Thus, start *Australis*, open a new project attaching the desired camera (BMP-DemoCam) and loading the 6 images of Demo1. Then, save the project under the desired name (no object point files are needed).

2. Select **Adjust/Relative Orientation.** The screen display will now be:



Select the appropriate two images for RO using the lists for 'left' and 'right' images (Images 1 and 2 in our case). Also, select **Scan Images** if the image points are suitable for autoscanning (they are in this case).

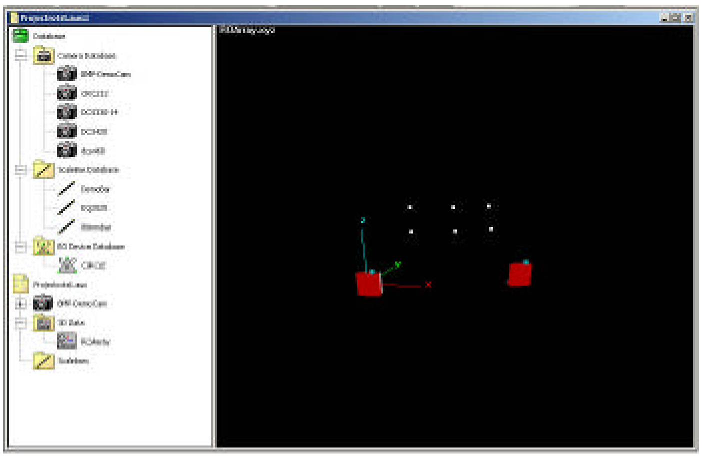
3. Measure the selected 6-10 points. In carrying out this operation, you can toggle between images and thus measure the first point in both images, followed by the second in both, etc. Or, you can measure all points in one image followed by all in the second. Or, you can mix the two. In order to have this flexibility, it is initially assumed that the point numbering for the RO points will be sequential from 1. This does not have to be the case and alternative labels can be used, but keeping the correct numbering/labelling when 'jumping' between images then becomes awkward. It is much more straightforward to stick with the default numbering of 1,2,3, etc. for the RO points. We will assume that the 6 points indicated in the figure below are the only ones required for RO. Note that image scanning has been selected.



4. Select **Compute RO** and wait until the **Accept** button is illuminated. By looking over the image coordinate residuals (v_{xy}) and the final RMS values, it is possible to ascertain the likelihood of a successful RO. Note that RO in this context is a preliminary process and residuals at the sub-pixel level would be the exception rather than the norm, especially with cameras that have not been fully calibrated. What you should look for here is an RMS figure that is down at the level of, say, 1-5 pixels. If the result looks reasonable, select **Accept.**

5. Upon acceptance of the RO, a file of XYZ coords for the RO'd points is attached to the **3D Data** tree under the name of *ROArray*. These points then become the 'driver points' (note the wheel on the icon) that are used for subsequent resection. Also, by utilising the graphics display of the *ROArray* and camera station positions, the operator gains a further level of confidence that the RO has been successfully performed, as indicated in the figure below.

6. At this stage the RO process per se is complete. The user now has a 'driver' file of resection control points as well the preliminary orientation of the first two images via RO. The orientation of subsequent images will via resection in the standard manner of *Australis* exterior orientation determination.

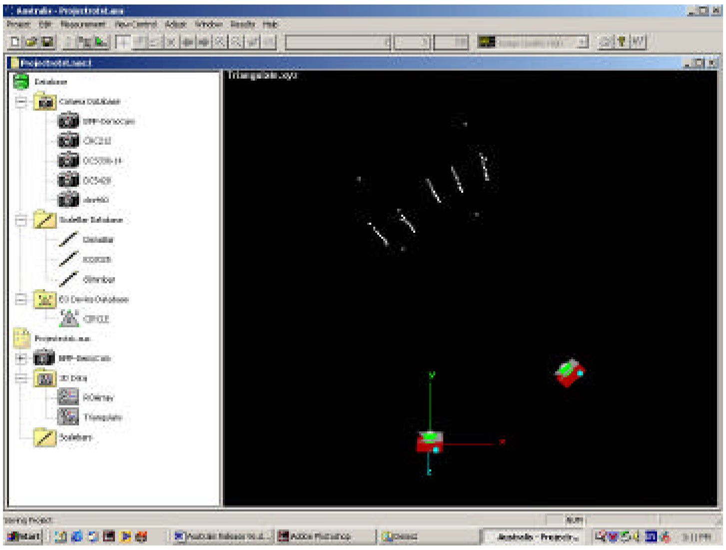


7. With the particular example used (*Australis* Demo 1), we have also used the Autoscan feature to qualify available targets. In the presence of a good RO result we can immediately densify the number of available 'driver' points using the following steps:

   a) Select **Measurement/Find Corresponding Points** (it might be useful to relax a few parameter values here, eg change *max epipolar angle difference* to 0.02 and *max error for* to 3 pixels). Note also that correspondence determination with only 2 images is likely to give some erroneous results, which may well be visible upon subsequent 3D graphics display.

   b) Select **Adjust/Triangulate** and then **Intersect** and **Accept**. The *Triangulate* file in the **3D Data** tree can now be graphically displayed, along with the camera stations. Here, there will be the RO'd points and all other points which have been successfully triangulated from the two RO images. For our example, this array of points is shown below.

   c) In order to use the full set of points as driver points for resection driveback, right click on the *Triangulate* data icon and set the file as the Driver.



Note in the figure that there are some obvious erroneous matches giving rise to intersection errors and grossly wrong XYZ coordinates for 4 points (with errors also for two others). The graphics display can be used to easily indicate these points. It is very worthwhile to then delete the wrong image measurements and to commence the sequential measurement process with a 'clean', reasonably correct driver file (remember, only approximate coordinates are needed for resection driveback, but they should be free of gross errors).

The remaining post-RO operation is as per the traditional *Australis* procedure of sequentially measuring each image with or without resection driveback, but using the driver points for exterior orientation via resection.

Also, recall, that the RO process can be geometrically very weak, thus leading to unstable or even no satisfactory solution. While this may occur, fortunately it is a reasonably infrequent occurrence. If it occurs, simply change the object points being used for the RO, or the two images involved.

10.5 Tutorial 5: Performing Interior Orientation

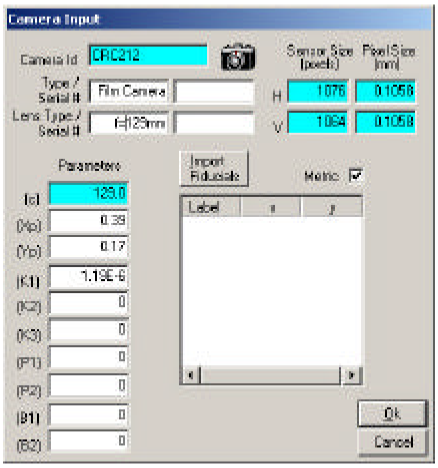
The Interior Orientation (IO) operation is only appropriate for scanned photogrammetric film images which have fiducial marks or reseaus. The section gives instructions for the performance of an IO for two image files provided with the ***Australis IO Demo***. The demo proceeds only as far as the spatial resection stage and there is no subsequent bundle adjustment or spatial intersection. It is assumed that the files provided have been installed as follows:

$:\australisdemo\interiororientation\pointdata\IO-CarDoorControl.xyz
$:\australisdemo\interiororientation\images\Door_IOTest.bmp
Door_IOTestRot.bmp

$:\australisdemo\ interiororientation \fiducials\CRC212.xy

1. Start *Australis* and select FILE|NEW to start a new project. Then, select the object space units, in this case millimetres (this is important for correct scaling of the graphics output – it does not effect the photogrammetric triangulation).

2. Either drag and drop camera ***CRC212*** from the ***Camera Database*** to the project, **OR** if this camera is not in the database, add a new camera to the camera database by right clicking on the ***Camera Database*** icon in the tree view. This new camera should have the camera parameters as shown in the figure below and after creation it should be dragged and dropped into the Project.



3. If adding a new camera, tick the ***Metric*** button in the Camera Input dialog (see figure above). From the ***Import Fiducials*** dialog, select the ***File*** button. From the resulting FILE OPEN dialog, select the file ***CRC212.xy*** from the directory ***$:\australisdemo\interiororientation\fiducials***. Close all dialogs. This operation imports the necessary fiducial mark coordinates (This step is not performed when a camera already present in the camera list is used).

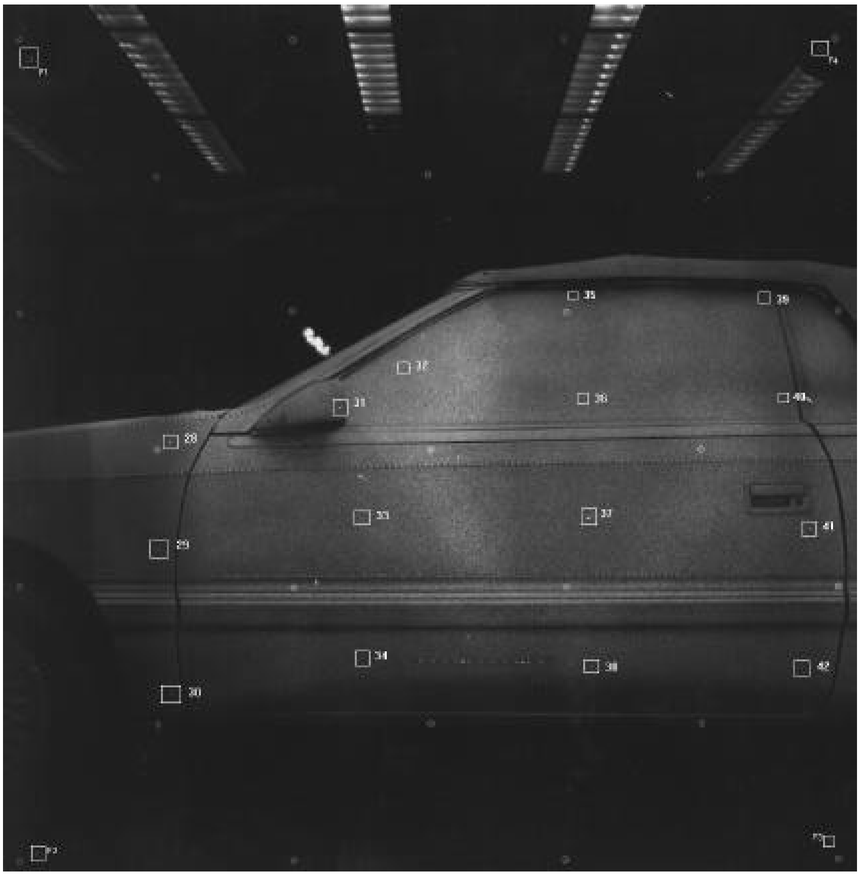
4. Right click on the Project camera icon (eg **CRC212**) and select ***Set Image File Directory***. This displays the *Select Image File Directory* dialog. Set the directory

to $:\AustralisDemo\InteriorOrientation\Images and press ok. Both images will be added to the project.

5. Save the project as ***$:\AustralisDemo\InteriorOrientation\projectname.aus*** using either the PROJECT|SAVE (or |SAVE AS) menu item or the floppy disk button on the tool bar. Note that the default directory for the project file is that containing the images. You will be prompted to save the project before proceeding beyond this point.

6. Right Click on the ***3D Data*** folder icon in the Project and select ***import*** and then ***Driveback file***. From the ***Browse 3D Data Files*** dialog, select file ***IO-CarDoorControl.xyz*** from the ***c:\AustralisDemo\InteriorOrientation\Point-data*** directory. This will then show as the driveback file under the ***3D Data*** icon.

7. Double click Image001 to display (the following large figure shows one of the two images).



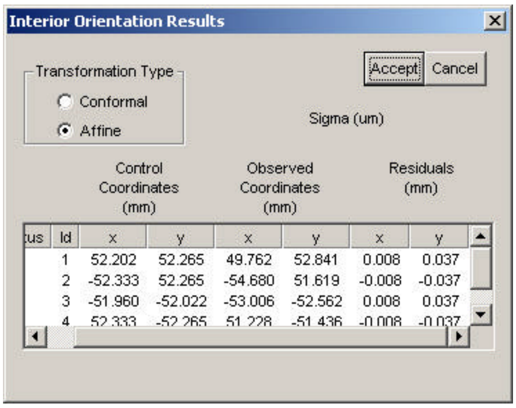
8. From the ***Measurement*** menu, select ***Interior Orientation Mode.*** The ***Interior Orientation Results*** dialog will be displayed. Automatic centroiding will be turned off and the cursor set to ZOOM. Move the ***Interior Orientation Results*** dialog out of the way of all fiducial marks.

9. Move the cursor to and zoom in to view the first fiducial. (Note: the fiducials have been artificially marked in these images, i.e. as F1, F2, F3, and F4; see the image

display figure, and the fiducial is the dot in the middle of the inner-most of the pair of marks) You may have to adjust the brightness to see the fiducial properly.

> **Note:** Ensure that the correct fiducial number (initially1) is visible in the point id edit box on the tool bar. Switch to digitise mode and measure Fiducial 1. You will need to point carefully as automeasure will have been turned off, so where you click is the recorded position.

10. Repeat step 9 for all four fiducials. You will have to drag the Interior Orientation Results dialog out of the way if it obscures points. After all fiducials have been measured, residuals from the affine or conformal transformation are displayed. You can toggle between the affine and conformal transformation solutions. Also, you can remeasure any fiducial you wish, but you must insert the correct point number first. Sample results for the transformation are shown in the figure below.



11. Choose the Affine radio button and press the Accept button in the upper right hand corner of the dialog. A confirmation dialog will be displayed. Upon acceptance, affine transformation parameters will be applied to all further measurements.

12. The remainder of the standard image coordinates can now be measured *manually* utilising the image point map of the car door provided above (Normally this is an automeasure operation but here the image quality does not support automatic centroiding). Note that after the IO procedure (acceptance of the transformation), the cursor reverts to Automeasure, so you will have to reset it to manual (untick ***Auto*** in the ***Measurement*** menu).

13. After measuring sufficient points, resect by right clicking on the image and selecting **Resect** from the resulting popup menu.

Steps 7-13 may be repeated for the second image of the car door. Beyond this point, the Australis process follows exactly as in Tutorial 1, through measurement and resection of all images and then bundle adjustment.

11. Appendix A: Hot Keys

The following key combinations are shortcuts for standard commands.

11.1 Image View

Alt + D	Resection Driveback
Alt + H	Measure Horizontal Plumbline
Alt + V	Measure Vertical Plumbline
Alt + R	Full Image View
Alt + S	Skip Point
Alt + M	Show Magnified View
Alt + A	AutoScan
Alt + E	EO device measurement mode
←	Opens previous image
→	Opens next image
↑	Increases image brightness
↓	Decreases image brightness
v	Toggles display of residual vectors
Alt + = (+)	Increase residual vector display scale
Alt + - (_)	Decrease residual vector display scale

11.2 3D Graphic View

>	Increase point intensity
<	Decrease point intensity
PgUp	Increase discrepancy vector display scale
PgDn	Decrease discrepancy vector display scale
↑	Zoom out
↓	Zoom in
} (])	Increase size of coordinate axes display
{ ([)	Decrease size of coordinate axes display
Ctrl + C	Toggle display of cameras in bundle.xyz
Ctrl + S	Toggle display of scalebars in bundle.xyz
Ctrl + V	Toggle display of discrepancy vectors in trans.xyz

12. Appendix B: *Australis* Image Coordinate System Description

12.1 Introduction

This appendix is intended to quell any confusion concerning the image coordinate system utilised in *Australis*. This is not a concern for projects in which image measurement and adjustment are both performed within *Australis*. However, if either one or the other is carried out in a different software package, the user must take care that the image coordinate system definitions are identical. Specifically, in the case that

1) If image coordinates measured in a separate program are imported into A*ustralis* for adjustment, or

2) If image coordinates measured in *Australis* are exported for adjustment in a separate program.

In either situation, if the image coordinate systems are not the same, a conversion to or from *Australis* image coordinates will be required.

12.2 Pixel and Image Coordinate Systems

The pixel and image coordinate systems used in *Australis* are shown in Figure 1. The pixel coordinate system origin is at the centre of the pixel at the top left of the sensor with the positive X-axis directed towards the right and the positive Y-axis directed downwards. The image coordinate system is centred on the sensor with the positive X-axis again directed towards the right and the positive Y-axis directed up. In Figure 1, the solid outer border represents the physical sensor extents, while the dashed interior border is meant as an aid in visualising the position of the pixel coordinate system.

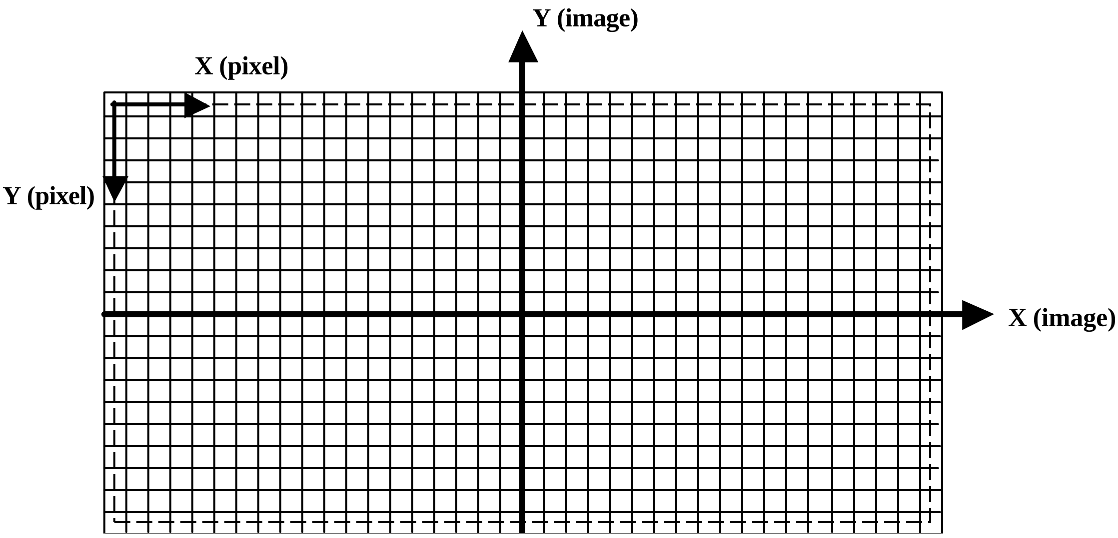


Figure 27: Australis coordinate systems. Image coordinate system is centred on the image while the pixel coordinate system origin is placed at the centre of the upper left, top pixel, with postive y downwards.

12.3 Converting from Pixel to Image Coordinate System

The location of an artificial target or natural feature measured either manually or by the centroid technique is recorded to sub pixel accuracy in the pixel coordinate system as shown in Figure 1. A half pixel is subtracted from both x and y to account for the fact that the pixel coordinate system is centred at the top left pixel. Before use in any adjustment, the measured coordinates are then converted to the image coordinate system as follows.

1) The centre of the sensor in the pixel coordinate system is determined by

$$CentreX = \left(\frac{nXPixels}{2}\right) - 0.5$$
$$CentreY = \left(\frac{nYPixels}{2}\right) - 0.5$$

2) The measured image coordinates are then

$$\text{XImage} = (XPixel - CentreX) \times XPixelSize$$
$$\text{YImage} = (CentreY - YPixel) \times YPixelSize$$

13. Appendix C: Sample *Australis* Output

13.1 Resection

```
                  Australis: Resection Results
                     21 February, 2001   20:27:01

Results for  Image001

 Station    Final        Final
Variable    Value       Accuracy

    X     1787.6574   9.6933E-002
    Y    -3417.8803   3.7875E-002
    Z     2440.6117   2.6038E-002
   AZ       13.5642   3.9367E-002
   EL      -15.5787   1.5877E-002
 ROLL      178.9910   2.2490E-003


Resected residuals for  Image001

               POINT     X Residual(um)     Y Residual(um)

                  11          -0.2               -0.4
                  12          -0.0               -0.1
                  13          -0.2               -0.1
                  14          -0.1                0.0
                  15          -0.2                0.3
                  21          -0.1               -0.2
                  22           0.1                0.1
                    …
                   … etc.
                   …
                   …
                  92          -0.0                0.1
                102          -0.2               0.2
                 103          -0.5                0.1
                 104          -0.2                0.2
                 105           0.1               -0.4

                 RMS           0.2                0.2
                 Total RMS     0.2
```

ETC…

13.2 Bundle Adjustment

13.2.1 Standard Output

```
                          Australis Bundle Adjustment Results File: Bundle.txt
                                      26 November, 2001   20:35:22

       Quick Summary
             Project: C:\AustralisDemo\Demo1\Demo1-Results\Demo1.aus
          Adjustment: Free Network
      Folding Method: Standard
             Scaling: Post Bundle
               Units: mm
    Number of Points: 50
    Number of Images: 6
Number of Scale Bars: 1
Number of Iterations: 3
    Elapsed CPU Time: 0.22  seconds

Post Bundle Scale Results

            Label        #              Label        #     Input      Measured     Distance
              1        Rays               2        Rays  Distance    Distance    Difference
             11          5               65          4   2217.1700   2217.1700      0.0000



             Adjusted Exterior Orientation Parameters (angles are decimal degrees, XYZ are mm)

Results for Station  Image001    FileName  Seq45.bmp     Camera BMP-DemoCam     Lens 20mm

 Station    Initial      Total        Final      Initial         Final
 Variable    Value     Adjustment     Value    Standard Error  Standard Error

    X      1788.7034     -0.0068   1788.6966    1.0000E+003    5.7350E-001
    Y     -3419.7280     -0.0008  -3419.7288    1.0000E+003    7.4269E-001
    Z      2440.9586      0.0301   2440.9887    1.0000E+003    4.7542E-001
   AZ        13.5582     -0.0002     13.5581    1.0000E+003    6.7906E-001
   EL       -15.5817     -0.0004    -15.5822    1.0000E+003    7.0804E-001
 ROLL       179.0036     -0.0000    179.0035    1.0000E+003    3.5017E-001
```

Results for Station Image002 FileName Seq05.bmp Camera BMP-DemoCam Lens 20mm

Station Variable	Initial Value	Total Adjustment	Final Value	Initial Standard Error	Final Standard Error
X	1853.4207	-0.0073	1853.4134	1.0000E+003	5.1776E-001
Y	-3633.9316	-0.0203	-3633.9519	1.0000E+003	7.8552E-001
Z	153.8809	0.0217	153.9026	1.0000E+003	5.0562E-001
AZ	15.5619	-0.0001	15.5618	1.0000E+003	6.9291E-001
EL	21.4063	-0.0004	21.4059	1.0000E+003	7.0751E-001
ROLL	-0.4555	-0.0000	-0.4556	1.0000E+003	4.1556E-001

…
…
… ETC.
…

Results for Station Image006 FileName Seq01.bmp Camera BMP-DemoCam Lens 20mm

Station Variable	Initial Value	Total Adjustment	Final Value	Initial Standard Error	Final Standard Error
X	-902.4136	-0.0168	-902.4304	1.0000E+003	5.7810E-001
Y	-3691.2881	-0.0124	-3691.3005	1.0000E+003	7.4802E-001
Z	147.9719	0.0179	147.9898	1.0000E+003	4.7799E-001
AZ	-26.8811	-0.0000	-26.8811	1.0000E+003	6.7006E-001
EL	20.2088	-0.0003	20.2085	1.0000E+003	7.3009E-001
ROLL	-6.9047	0.0003	-6.9044	1.0000E+003	4.0402E-001

Summary of Image Coordinate Residuals (units are micrometres)

Sta #	RMS of Image Residuals x	y	xy	Number of non-rejected points
Image001	0.18	0.20	0.19	50
Image002	0.16	0.14	0.15	50
Image003	0.30	0.47	0.40	39
Image004	0.16	0.16	0.16	30
Image005	0.21	0.15	0.18	50
Image006	0.31	0.19	0.26	50

Total Residuals (RMS) x	y	xy	Sigma0	Degrees of Freedom	Observations	Parameters	Constraints
0.23	0.24	0.23	0.485	501	538	196	159

Standard Errors From Limiting Error and Total Error Propogation (XYZ are in mm)

	Limiting Sigma Estimates			Total Sigma Estimates					Sightings List 1111111111222222222223
Label	sX	sY	sZ	sX	sY	sZ	RMS	# Rays	123456789012345678901234567890
11	0.0221	0.0449	0.0209	0.0262	0.0490	0.0246	0.3	5	YY*YYY
12	0.0188	0.0412	0.0196	0.0212	0.0419	0.0209	0.4	6	YYYYYY
13	0.0201	0.0472	0.0207	0.0216	0.0481	0.0242	0.3	6	YYYYYY
14	0.0251	0.0519	0.0239	0.0279	0.0515	0.0256	0.3	5	YYYNYY
15	0.0275	0.0588	0.0256	0.0327	0.0630	0.0307	0.2	4	YYNNYY
21	0.0187	0.0409	0.0192	0.0201	0.0436	0.0206	0.4	6	YYYYYY
22	0.0188	0.0410	0.0191	0.0212	0.0420	0.0206	0.3	6	YYYYYY
…									
…									
… ETC.									
…									
94	0.0253	0.0507	0.0216	0.0270	0.0504	0.0227	0.3	5	YYYNYY
95	0.0275	0.0567	0.0243	0.0313	0.0580	0.0272	0.1	4	YYNNYY
101	0.0181	0.0397	0.0177	0.0223	0.0486	0.0214	0.5	6	YYYYYY
102	0.0185	0.0397	0.0181	0.0207	0.0401	0.0202	0.2	6	YYYYYY
103	0.0203	0.0459	0.0196	0.0214	0.0468	0.0230	0.2	6	YYYYYY
104	0.0253	0.0505	0.0216	0.0265	0.0497	0.0230	0.4	5	YYYNYY
105	0.0274	0.0564	0.0243	0.0340	0.0587	0.0298	0.2	4	YYNNYY

	Summary of Limiting STD Error Estimates			Summary of Total STD Error Estimates		
	X	Y	Z	X	Y	Z
RMS is	0.0224	0.0477	0.0208	0.0248	0.0496	0.0225
Minimum is	0.0181	0.0397	0.0177	0.0190	0.0401	0.0181
at point	101	102	91	41	102	61
Maximum is	0.0276	0.0588	0.0256	0.0340	0.0630	0.0307
at point	75	15	15	105	15	15

Triangulated Object Space Coordinates (XYZ are in mm)

Label	X	Y	Z	RMS	# Rays	Sightings List 1111111111222222222223 123456789012345678901234567890
11	-83.3378	-283.0137	2189.7323	0.3	5	YY*YYY
12	410.9437	-286.6406	2182.9382	0.4	6	YYYYYY
13	1028.9717	-36.5983	2183.8520	0.3	6	YYYYYY
14	1464.0432	-30.4780	2182.1954	0.3	5	YYYNYY

```
  15   1962.7297    -28.7270   2179.8744   0.2    4      YYNNYY
                 …
  …
  … ETC.
  …

  83   1047.3752     -7.1235   1156.0437   0.1    6      YYYYYY
  84   1482.9998     -4.6887   1145.2279   0.2    5      YYYNYY
  85   1974.4774     -4.1900   1152.7266   0.1    4      YYNNYY
  91    -87.2180   -288.8214   1021.8410   0.3    6      YYYYYY
  92    432.4906   -291.5680   1032.6039   0.2    6      YYYYYY
  93   1050.1395     -7.5789   1034.1734   0.2    6      YYYYYY
  94   1482.7969     -5.8114   1030.2886   0.3    5      YYYNYY
  95   1976.3257     -4.5677   1027.6914   0.1    4      YYNNYY
 101    -91.4325   -288.7467    902.4639   0.5    6      YYYYYY
 102    429.8676   -291.8781    907.0290   0.2    6      YYYYYY
 103   1049.1224     -7.9173    909.2066   0.2    6      YYYYYY
 104   1483.3399     -6.1398    911.1188   0.4    5      YYYNYY
 105   1977.1755     -5.8383    914.4262   0.2    4      YYNNYY

Image Coordinate Rejections


Image Number Image001

Image Number Image002

Image Number Image003
 11
Image Number Image004

Image Number Image005

Image Number Image006

Total Rejections   1
```

13.2.2 Camera Output

Australis Bundle Adjustment Results: Camera Parameters
26 November, 2001 20:35:22

Project: C:\AustralisDemo\Demo1\Demo1-Results\Demo1.aus

Adjustment: Free-Network
Number of Points: 50
Number of Images: 6
RMS of Image coords: 0.23 (um)

Results for Camera 1 BMP-DemoCam Lens 20mm

Sensor	Size	Pixel Size (mm)
H	1524	0.009
V	1012	0.009

Camera Variable	Initial Value	Total Adjustment	Final Value	Initial Std. Error	Final Std. Error
C	20.3830	0.00001	20.3830	1.0e+003	3.368e-003 (mm)
XP	0.0937	-0.00002	0.0937	1.0e+003	2.700e-003 (mm)
YP	0.0702	0.00000	0.0702	1.0e+003	3.377e-003 (mm)
K1	2.36392e-004	9.941e-008	2.36491e-004	1.0e+003	5.283e-006
K2	2.69044e-007	-3.683e-009	2.65360e-007	1.0e+003	1.831e-007
K3	-6.53174e-009	4.654e-011	-6.48520e-009	1.0e+003	1.986e-009
P1	7.39063e-006	-6.054e-007	6.78520e-006	1.0e+003	2.329e-006
P2	1.21095e-005	4.550e-007	1.25645e-005	1.0e+003	2.783e-006
B1	3.41866e-027	2.927e-028	3.71132e-027	1.0e-016	4.847e-017
B2	-6.07214e-027	-6.482e-028	-6.72032e-027	1.0e-016	4.847e-017

Maximum Observational Radial Distance Encountered: 7.6 mm

Exterior Orientation Summary (Xc, Yc, Zc are in project units, rotations are in decimal degrees)

Station	Image	Xc	Yc	Zc	Alpha	Elev.	Roll
1	Image001	1788.69659	-3419.72879	2440.98873	13.558074	-15.582166	179.003534
2	Image002	1853.41338	-3633.95192	153.90262	15.561791	21.405924	-0.455581
3	Image003	-766.05593	-3486.66554	857.24939	-23.245430	10.304050	-91.797034
4	Image004	1877.17657	-3598.03953	1975.30470	22.174863	-7.402492	88.950822
5	Image005	-638.09728	-3533.53957	1980.03752	-23.096045	-7.344403	-178.399762
6	Image006	-902.43042	-3691.30052	147.98981	-26.881088	20.208480	-6.904405

13.2.3 Residual Output

```
            Australis Bundle Adjustment Results: Image Coordinate Residuals
                             21 February, 2001   21:36:55

Project:  C:\AustralisDemo\Demo1\Test44.aus

Adjustment is Free-Network -- There are no explicit control points ***

            Triangulated residuals

 Sta  |Pt 11              |Pt 12              |Pt 13              |Pt 14              |Pt 15              |
  #   |      x       y    |      x       y    |      x       y    |      x       y    |      x       y    |
   1  |     -0.1    -0.4  |      0.0    -0.2  |     -0.2    -0.1  |     -0.1    -0.0  |     -0.1     0.3  |
   2  |     -0.2    -0.2  |      0.0    -0.2  |     -0.3     0.1  |     -0.0    -0.3  |      0.0    -0.1  |
   3  |     -0.2*   -2.1* |     -0.5    -0.7  |     -0.4     0.0  |     -0.5     0.5  |      0.0N    0.0N |
   4  |     -0.3     0.4  |      0.2     0.1  |      0.1    -0.3  |      0.0N    0.0N |      0.0N    0.0N |
   5  |      0.1    -0.3  |     -0.5     0.4  |     -0.2     0.5  |      0.2     0.2  |      0.1    -0.1  |
   6  |      0.4    -0.3  |      0.3    -0.5  |     -0.4    -0.1  |     -0.4    -0.0  |     -0.2     0.3  |

 Sta  |Pt 21              |Pt 22              |Pt 23              |Pt 24              |Pt 25              |
  #   |      x       y    |      x       y    |      x       y    |      x       y    |      x       y    |
   1  |     -0.0    -0.3  |      0.1     0.0  |      0.2    -0.3  |      0.0    -0.1  |     -0.1     0.3  |
   2  |      0.0    -0.0  |      0.1     0.0  |     -0.2     0.1  |      0.1    -0.1  |      0.1    -0.0  |
   3  |      0.0    -1.1  |     -0.3    -0.7  |     -0.1     0.1  |     -0.2     0.5  |      0.0N    0.0N |
   4  |     -0.3     0.1  |      0.1     0.0  |     -0.1    -0.3  |      0.0N    0.0N |      0.0N    0.0N |
   5  |     -0.3    -0.0  |     -0.3     0.1  |     -0.1     0.3  |      0.2     0.1  |      0.2    -0.1  |
   6  |      0.8     0.1  |      0.4    -0.3  |     -0.3    -0.1  |     -0.3    -0.1  |     -0.1     0.3  |

 Sta  |Pt 31              |Pt 32              |Pt 33              |Pt 34              |Pt 35              |
  #   |      x       y    |      x       y    |      x       y    |      x       y    |      x       y    |
   1  |      0.0    -0.2  |      0.2     0.2  |      0.3    -0.3  |      0.1    -0.2  |      0.0     0.3  |
   2  |      0.0     0.1  |      0.1    -0.0  |     -0.2    -0.0  |      0.0    -0.2  |      0.2     0.1  |
   3  |      0.2    -0.8  |     -0.1    -0.4  |      0.2     0.2  |      0.1     0.5  |      0.0N    0.0N |
   4  |     -0.2     0.0  |      0.2    -0.1  |     -0.1    -0.2  |      0.0N    0.0N |      0.0N    0.0N |
   5  |     -0.2    -0.1  |     -0.2     0.0  |     -0.2    -0.0  |      0.2    -0.0  |      0.2    -0.3  |
   6  |      0.6     0.1  |      0.2    -0.1  |     -0.2    -0.1  |     -0.2     0.1  |     -0.1     0.1  |

 Sta  |Pt 41              |Pt 42              |Pt 43              |Pt 44              |Pt 45              |
  #   |      x       y    |      x       y    |      x       y    |      x       y    |      x       y    |
   1  |     -0.0    -0.2  |      0.2     0.1  |      0.3    -0.4  |      0.1    -0.2  |      0.0     0.3  |
   2  |      0.0     0.1  |      0.2    -0.1  |     -0.1    -0.0  |     -0.0    -0.0  |      0.3     0.4  |
   3  |      0.3    -0.5  |     -0.0    -0.1  |      0.4     0.2  |      0.3     0.4  |      0.0N    0.0N |
   4  |     -0.2    -0.0  |      0.2    -0.1  |     -0.1    -0.2  |      0.0N    0.0N |      0.0N    0.0N |
   5  |      0.0    -0.0  |      0.1    -0.0  |     -0.1    -0.1  |      0.2    -0.1  |      0.1    -0.0  |
   6  |      0.4     0.2  |      0.3     0.0  |     -0.1    -0.0  |     -0.1     0.0  |     -0.4    -0.1  |
```

Etc…

Summary of Residuals

Sta #	Station Residuals x	y	Total	Number of Points
Image001	0.18	0.20	0.19	50
Image002	0.16	0.14	0.15	50
Image003	0.30	0.47	0.39	39
Image004	0.15	0.16	0.16	30
Image005	0.21	0.15	0.18	50
Image006	0.31	0.20	0.26	50

Total Residuals x	y	Total	Observations	Constraints	Parameters	Degrees of Freedom	Mean Error of Unit Weight
0.23	0.24	0.23	538	159	196	501	0.485

13.2.4 Correlation Output

Australis Bundle Adjustment Results: Correlation Matrices
21 February, 2001   21:36:55

Project: C:\AustralisDemo\Demo1\Test44.aus

Camera Correlation Matrix

	C	XP	YP	K1	K2	K3	P1	P2	B1	B2
C	1.000	-0.282	0.750	0.241	-0.262	0.226	0.214	-0.634	-0.000	-0.000
XP		1.000	-0.236	-0.100	0.132	-0.117	-0.957	0.217	0.000	0.000
YP			1.000	-0.027	-0.052	0.043	0.196	-0.941	-0.000	-0.000
K1				1.000	-0.941	0.880	0.080	0.065	-0.000	-0.000
K2					1.000	-0.981	-0.116	0.010	-0.000	0.000
K3						1.000	0.101	0.006	0.000	-0.000
P1							1.000	-0.189	-0.000	0.000
P2								1.000	-0.000	0.000
B1									1.000	-0.000
B2										1.000

Correlations between Camera and Image EO Parameters

Image 1: Seq45.bmp

	X	Y	Z	A	E	R
C	0.708	-0.918	0.417	-0.037	-0.727	0.125
XP	-0.289	0.273	-0.009	0.862	0.196	-0.901
YP	0.549	-0.817	0.135	-0.064	-0.922	0.162
K1	0.020	0.058	0.019	-0.073	0.006	0.072
K2	-0.117	0.039	-0.015	0.064	0.051	-0.081
K3	0.096	-0.028	0.039	-0.061	-0.053	0.072
P1	0.154	-0.237	-0.037	-0.903	-0.147	0.923
P2	-0.456	0.713	-0.133	0.079	0.890	-0.164
B1	-0.000	0.000	0.000	0.000	-0.000	-0.000
B2	-0.000	0.000	0.000	-0.000	0.000	0.000

…
…etc.
…

Image 6: Seq01.bmp

	X	Y	Z	A	E	R
C	-0.924	-0.918	-0.837	0.076	0.750	0.087
XP	0.287	0.243	0.222	-0.943	-0.324	-0.883
YP	-0.764	-0.778	-0.604	0.016	0.977	0.069
K1	0.018	0.058	-0.080	0.088	0.022	0.017
K2	0.032	0.033	0.113	-0.123	-0.090	-0.073
K3	-0.012	-0.032	-0.093	0.121	0.074	0.079
P1	-0.210	-0.206	-0.151	0.934	0.273	0.889
P2	0.641	0.683	0.523	-0.031	-0.925	-0.074
B1	0.000	0.000	-0.000	0.000	-0.000	-0.000
B2	0.000	-0.000	0.000	-0.000	-0.000	0.000

13.3 3D Transformation

```
                  Australis Results: 3D Transformation
                          21 February, 2001   20:28:21


            Quick Summary

                  Control: C:\AustralisDemo\Demo1\Object.xyz
      Points to Transform: C:\AustralisDemo\Demo1\Bundle.xyz
  Transformed Coordinates: C:\AustralisDemo\Demo1\Trans.xyz
  Number of Common Points: 50
Number of Rejected Points: 3
     Number of Iterations: 6
         RMS of residuals: 0.0193
                   Sigma0: 0.0198
    Residual Error Cutoff: 0.0700


            Final Transformation Parameters

              Parameter     Standard Error

   Xo          -0.689347      0.007007
   Yo          -0.350286      0.011886
   Zo           1.317747      0.007066
Scale           1.000515      0.000004
Omega          -0.005142      0.000413
  Phi           0.011645      0.000210
Kappa           0.001289      0.000229


                       Secondary Coordinate Residuals

           Label              VX             VY             VZ

              11       -0.07734        0.11670       -0.00081  ** rejected **
              12       -0.02983        0.00179       -0.00172
              13       -0.00954        0.01371        0.01501
              14       -0.02008       -0.03060       -0.02488
              15       -0.07636       -0.08455       -0.08237  ** rejected **
              21        0.00124        0.01148       -0.01388
              22       -0.03286       -0.00106        0.00383
              23       -0.00439        0.01760        0.01685
              24       -0.00290       -0.01447       -0.00997
              25       -0.06499       -0.07751       -0.06490  ** rejected **
              31       -0.00402        0.01358       -0.00427
              32       -0.03350       -0.00814        0.00395
       …
```

…etc.

…

102	-0.00424	-0.02954	0.00601
103	0.00885	-0.01066	-0.00386
104	0.04148	0.02635	0.00204
105	0.00008	0.02662	0.02866

RMS Values: 0.02255 0.01943 0.01518 RMS XYZ = 0.01929

	Transformed Coordinates			Differences		
Label	X	Y	Z	DX	DY	DZ
11	-83.30981	-283.09095	2189.68378	0.07738	-0.11676	0.00082
12	410.95906	-286.70085	2182.88270	0.02985	-0.00179	0.00173
13	1028.96406	-36.63866	2183.80960	0.00955	-0.01371	-0.01502
14	1464.02462	-30.50664	2182.14929	0.02008	0.03061	0.02490
15	1962.70598	-28.74141	2179.82809	0.07639	0.08458	0.08243
21	-79.71844	-284.47689	2041.43308	-0.00125	-0.01149	0.01389
22	375.45032	-288.46030	2035.53770	0.03288	0.00106	-0.00382
23	1034.05377	-37.76455	2027.99146	0.00439	-0.01761	-0.01686
…						
… etc.						
…						
101	-91.40240	-288.73416	902.46129	-0.04021	0.01323	-0.04570
102	429.87495	-291.85885	907.01439	0.00424	0.02955	-0.00601
103	1049.10353	-7.88306	909.19973	-0.00885	0.01067	0.00386
104	1483.31002	-6.09403	911.10661	-0.04150	-0.02637	-0.00205
105	1977.13946	-5.78070	914.40526	-0.00008	-0.02663	-0.02868

RMS Without Rejected Points: 0.02256 0.01944 0.01519

RMS XYZ: 0.01930

RMS With Rejected Points: 0.02827 0.02985 0.02091

RMS XYZ: 0.02663

13.4 Best-Fit Functions

13.4.1 Best Fit Line

```
            Australis Results: Best Fit Line
              11 August, 1999   16:58:26


       Quick Summary

    Number of Points: 10
     Rejected Points: 0
          Iterations: 11
    RMS of residuals:  5.68418
              Sigma0:  6.22671
Residual Error Cutoff: 1000.00000


    Line Parameters

                 Xo: 1981.229778
                 Yo:    0.000000
                 Zo: 544.340946
                  u:   -0.006960
                  v:   -0.021465
                  w:    0.999745
```

Coordinate Residuals (Departures from Best-Fit Line)

Label	X	Y	Z	VX	VY	VZ	VXYZ
15	1962.62897	-28.82430	2179.74484	-7.21823	6.28896	0.08478	9.57398
25	1971.84918	-29.43300	2031.75925	0.97506	2.50297	0.06052	2.68687
35	1969.86819	-31.37187	1880.37529	-2.05890	-2.68384	-0.07194	3.38337
45	1972.56938	-33.40734	1727.66659	-0.41862	-7.99633	-0.17457	8.00919
55	1975.75028	-34.67249	1579.15715	1.73039	-12.44881	-0.25520	12.57109
65	1981.12588	-34.67170	1420.28492	6.00205	-15.85868	-0.29867	16.95911
75	1982.77854	-2.51019	1277.33833	6.64732	13.21972	0.33005	14.80057
85	1974.43913	-4.14389	1152.70978	-2.56072	8.91315	0.17352	9.27532
95	1976.28757	-4.50250	1027.68798	-1.58148	5.87110	0.11503	6.08145
105	1977.13940	-5.75154	914.43507	-1.51686	2.19178	0.03650	2.66572
			RMS	3.89914	9.03831	0.18826	9.84529

13.4.2 Best Fit Plane

```
              Australis Results: Best Fit Plane
                   11 August, 1999   16:56:26

          Quick Summary

       Number of Points: 30
        Rejected Points: 0
             Iterations: 2
       RMS of residuals: 8.7142
  Residual Error Cutoff: 26.1427


       Plane Parameters

                    A: -0.005
                    B:  1.000
                    C:  0.027
                    D: -11.578

              Residuals

                  Label     Residual

                     13      6.79617
                     14     10.70422
                     15      9.90815
                     23      1.36640
                     24      5.20209
                     25      5.18705
                     33     -3.05561
                     34     -0.20628
                     35     -0.90225
                     43     -7.35767
                     44     -5.41673
                        …
                        …etc.
                        …

                     93      4.14867
                     94      3.73217
                     95      2.48855
                    103      0.38264
                    104      0.13420
                    105     -1.87700

                    RMS      8.71420
```

13.4.3 Best Fit Circle

```
                    Australis Results: Best Fit Circle
                       20 October, 1999   14:04:21
Quick Summary

         Number of Points: 49
          Rejected Points: 0
               Iterations: 4
         RMS of residuals: 3.8807
    Residual Error Cutoff: 11.6420


         Circle Parameters

                        Xo: 5455.876
                        Yo: 2455.083
                        Zo: 2378.190
                         R: 3917.324

                Residuals

                    Label     Residual

                       25     -7.63056
                       26     -5.67758
                       27     -4.50205
                       28     -3.59227
                       29     -3.21768
                       30     -1.74174
                       31     -0.31885
                       32      1.53639
                       33      3.07335
                       34      4.15235
                       35      4.49120
                       36      5.09862
                          …
                          … etc.
                          …
                       69     -0.27568
                       70     -1.00143
                       71     -2.89842
                       72     -3.39797
                       73     -4.53536

                      RMS      3.88066
```

13.4.4 Best Fit Sphere

```
                  Australis Results: Best Fit Sphere
                   20 October, 1999   14:05:14
     Quick Summary

         Number of Points: 24
          Rejected Points: 0
               Iterations: 5
         RMS of residuals: 0.0081
    Residual Error Cutoff: 0.0244


         Sphere Parameters

                        Xo:    0.001
                        Yo:    8.141
                        Zo:   -0.015
                         R:    3.910

                Residuals

                    Label     Residual

                    1138      0.00334
                     1139     -0.00044
                     1140      0.00494
                     1141      0.00588
                     1142      0.00404
                     1143      0.01029
                     1144     -0.01714
                     1145     -0.00021
                     1146     -0.00902
                     1147     -0.00287
                     1148     -0.02059
                     1149     -0.00581
                     1150     -0.00740
                     1151     -0.00583
                     1152      0.00446
                     1153      0.00522
                     1154     -0.00758
                     1155      0.00637
                     1156      0.00393
                     1157      0.00785
                     1158     -0.00206
                     1159      0.00250

                      RMS      0.00814
```

13.5 Triangulation

Australis Results: Triangulation
21 February, 2001 21:35:34

Quick Summary
Project: C:\AustralisDemo\Demo1\Test44.aus
Number of Points: 50
Number of Images: 6

Stations Used

FileName	X	Y	Z	Azimuth	Elevation	Roll
Seq45.bmp	1814.7573	-3433.5120	2437.2603	13.5619	-15.6360	179.0076
Seq05.bmp	1848.0030	-3653.9937	142.7191	15.8006	21.6588	-0.3472
Seq11.bmp	-774.1859	-3496.0633	849.5344	-23.5066	10.7608	-91.9078
Seq30.bmp	1884.8347	-3619.6522	1973.3173	22.3580	-7.6976	88.9508
Seq31.bmp	-644.1330	-3557.0841	1976.9736	-23.4088	-7.4449	-178.4217
Seq01.bmp	-920.2665	-3695.8416	147.6548	-26.7047	20.4154	-6.8262

Summary of Residuals

	Station	Station Residuals			Number of
Filename	#	X	Y	Total	Points
Seq45.bmp	1	3.36	1.58	2.63	50
Seq05.bmp	2	2.28	3.59	3.01	50
Seq11.bmp	3	2.52	3.64	3.13	40
Seq30.bmp	4	3.16	5.68	4.60	30
Seq31.bmp	5	2.22	4.74	3.70	50
Seq01.bmp	6	2.54	7.73	5.76	50

Total Residuals

X	Y	Total
2.69	4.86	3.93

	Point Coordinates			Standard Errors				#	Sightings List 1111111111222222222233333333334
Label	X	Y	Z	X	Y	Z	RMS	Rays	1234567890123456789012345678901234567890
11	-83.3905	-282.9801	2189.6747	0.0014	0.0020	0.0015	0.1	6	YYYYYY
12	410.9346	-286.6349	2182.8934	0.0024	0.0035	0.0025	0.2	6	YYYYYY
13	1028.9331	-36.8009	2183.7988	0.0080	0.0119	0.0081	0.8	6	YYYYYY
14	1464.0412	-30.4125	2182.1455	0.0063	0.0091	0.0065	0.5	5	YYYNYY
15	1962.4943	-28.8263	2179.6313	0.0327	0.0494	0.0337	2.6	4	YYNNYY
21	-79.8986	-284.5062	2041.4619	0.0090	0.0130	0.0092	0.9	6	YYYYYY
22	375.2925	-288.4275	2035.5225	0.0063	0.0091	0.0064	0.6	6	YYYYYY
23	1033.8880	-37.8562	2028.0283	0.0130	0.0196	0.0131	1.2	6	YYYYYY

24	1466.0465	-31.7443	2028.3928	0.0100	0.0147	0.0102	0.9	5	YYYNYY
25	1971.5315	-29.5052	2031.7622	0.0336	0.0511	0.0343	2.7	4	YYNNYY
31	-82.6268	-285.4632	1887.7758	0.0164	0.0241	0.0167	1.6	6	YYYYYY
32	415.8791	-289.0785	1881.5903	0.0131	0.0191	0.0132	1.3	6	YYYYYY
33	1032.1675	-38.2324	1881.7791	0.0191	0.0288	0.0191	1.8	6	YYYYYY
34	1467.8438	-33.0651	1877.1649	0.0173	0.0255	0.0174	1.5	5	YYYNYY
35	1969.3344	-31.5451	1880.4794	0.0361	0.0551	0.0366	2.9	4	YYNNYY
41	-80.4475	-286.9442	1736.9539	0.0234	0.0346	0.0236	2.3	6	YYYYYY
	…								
	… etc.								
	…								
93	1049.0868	-7.4707	1035.0840	0.0663	0.1001	0.0655	6.3	6	YYYYYY
94	1480.8356	-6.0278	1031.3112	0.0641	0.0959	0.0627	5.6	5	YYYNYY
95	1974.0012	-5.5753	1028.7341	0.0718	0.1094	0.0718	5.7	4	YYNNYY
101	-92.2683	-289.3157	903.2382	0.0623	0.0923	0.0620	6.3	6	YYYYYY
102	428.7434	-292.0658	907.5270	0.0630	0.0914	0.0622	6.2	6	YYYYYY
103	1047.9823	-7.7697	910.2399	0.0750	0.1125	0.0743	7.2	6	YYYYYY
104	1481.2024	-6.3398	912.3391	0.0725	0.1082	0.0709	6.3	5	YYYNYY
105	1974.5739	-6.9730	915.7042	0.0773	0.1173	0.0774	6.1	4	YYNNYY

	X	Y	Z
RMS is	0.0436	0.0655	0.0433
Minimum is	0.0014	0.0020	0.0015
at point	11	11	11
Maximum is	0.0773	0.1173	0.0774
at point	105	105	10

13.6 Balancing Radial Distortion

(file: balance.txt)

```
Australis Results: Output of Lens Distortion Data


1. Gaussian Lens Distortion

Camera: BMP-DemoCam
Project: C:\AustralisDemo\Demo1\Demo1-Results\Demo1.aus
Date: 26 November, 2001   20:32:16

For principal distance c, radial distortion correction dr (microns) is
given for any radial distance r (mm) as:

dr = K1*r^3 + K2*r^5 + K3*R^7
correction dx = x·dr/r
correction dy = y·dr/r

c  =        20.383
K1 =  2.36491e-004
K2 =  2.65360e-007
K3 = -6.48520e-009

             r (mm)                dr (microns)
             0.0                   0.0
             1.0                   0.2
             2.0                   1.9
             3.0                   6.4
             4.0                  15.3
             5.0                  29.9
             6.0                  51.3
             7.0                  80.2
             8.0                 116.2
             9.0                 157.1
            10.0                 198.2
            11.0                 231.1
            12.0                 242.3
```

2. Balanced Radial Lens Distortion

Camera: BMP-DemoCam
Project: C:\AustralisDemo\Demo1\Demo1-Results\Demo1.aus
Date: 26 November, 2001 20:32:16

For 'balanced' principal distance cb, radial distortion correction dr(microns) is given for any radial distance r (mm) as:
dr = k0*r + k1*r^3 + k2*r^5 + k3*r^7

cb = 20.152 mm
k0 = -1.13323e-002
k1 = 2.33811e-004
k2 = 2.62353e-007
k3 = -6.41171e-009

r (mm)	dr (microns)
0.0	0.0
1.0	-11.1
2.0	-20.8
3.0	-27.6
4.0	-30.2
5.0	-27.1
6.0	-17.2
7.0	-0.0
8.0	24.2
9.0	53.3
10.0	82.6
11.0	103.9
12.0	103.6

Curve balanced about a radial distance of 7.0 mm