

USERS MANUAL for *XYRectify*

Program Function

XYRectify creates rectified images from oblique images of planar surfaces. This operation is often referred to in photography circles as “keystoning” or removing the keystone effect. It takes place, for example, when an image taken looking up at a building is transformed to one where vertical edges of the building become both parallel and ‘vertical’, as indicated in Figure 1. Whereas image scale is not homogeneous in the oblique or tilted image, it is homogeneous in the rectified image. This allows XY coordinates with consistent scale to be digitized in the rectified image. Shown in the figures below are oblique or tilted images (with respect to the plane of interest) and the corresponding rectified images for the planar surface of interest. Note in Figure 1 how in the rectified image the window frames are now parallel or orthogonal, and in Figure 2 the carpet is rectangular, as if viewed from directly above its centre.

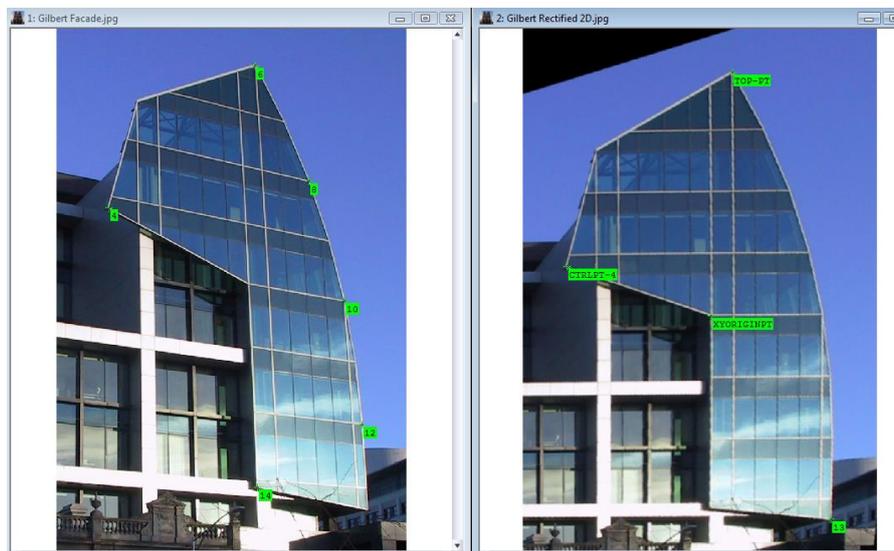


Figure 1: Unrectified (left) and rectified image (right) of building façade.



Figure 2: Unrectified (left) and rectified image (right) of ‘Bailey’.

Input for *XYRectify*

1. One or more images (assumed to be tilted) of the planar reference surface.
2. Photogrammetric calibration parameters for the digital camera, which is optional depending upon both the accuracy required in the rectification and the rectification approach adopted (so-called 2D or 3D options). This data can be either input manually, or read directly from a designated *iWitness* or *iWitnessPRO* project file containing the same, calibrated camera.
3. (a) The 2D XY coordinates of four or more points on the reference surface (these can be real or fictitious) if the Projective Transformation option is selected; or
(b) The 3D XYZ coordinates of four or more points (where the plane $Z=0$ defines the reference surface) in cases where the Resection option is selected.

Output from *XYRectify*

1. One or more rectified images, saved as JPEGs and accompanied by 'tfw' or 'World files' which define the XY coordinate system for the rectified image.
2. Digitised XY point coordinates from the rectified image, which can be output as a text file (point label, X, Y) or in DXF format for input into a CAD system.
3. A results summary for either the projective transformation between the xy coordinates of measured image points in the oblique image and the corresponding XY coordinates of 'control' points in the reference plane, or the spatial resection of the image(s) from the 3D XYZ control points. A least-squares estimation is performed in both cases when more than four control points are available, which is always recommended.

Process

a) Projective Transformation

The 2D rectification process can be summarised as follows:

1. Assume the XY (ie 2D) coordinates of 4 or more control points on a planar surface are known, as indicated by the marked points in Figure 2.
2. Further assume that there is an oblique or tilted image of the surface in which the control points can be identified. Within *XYRectify*, the xy coordinates of these points need to be measured (the program assigns the xy reference system).
3. A projective transformation is then computed such that xy image coordinates can be 'mapped' to XY reference plane coordinates. Thus, the position of any point on the original image can be expressed in XY coordinates.
4. A rectified image with homogeneous scale (essentially equivalent to an orthographic 'map' projection) is then generated, as indicated in Figures 1 & 2. In *XYRectify*, the user can also export either the whole rectified image, or a rectangular section of the rectified image, by 'cutting out' the region of interest.
5. The user can digitise desired XY coordinates from this rectified image, or after the *XYRectify* run, can import the new JPEG image into a CAD or GIS system to enable true-scale XY planar coordinate measurements. These will be free of the tilt distortion inherent in the original image.

b) Spatial Resection

The 3D rectification approach can be summarised as:

1. Assume the XYZ (ie 3D) coordinates of 4 or more control points, which may or may not be co-planar, are known, as indicated by the marked points in Figure 2.
 2. Further assume that there is an oblique or tilted image of the surface in which the control points can be identified. Within *XYRectify*, the xy coordinates of these points need to be measured.
 3. A spatial resection is then computed such that the exterior orientation of the image with respect to the XY rectification plane ($Z = 0$) is determined and xy image coordinates can be 'mapped' to XY reference plane coordinates. Thus, the position of any point on the original image can be expressed in XY coordinates.
- 4 & 5. The same as in 4 and 5 for the projective transformation approach above.

Operational Steps

The building façade in Figure 1 will be used to illustrate the steps of *XYRectify*.

1. *Acquire the oblique/tilted image* of the surface of interest in either JPEG or Tiff format. For the 2D *projective transformation* approach, either a full or cropped image from a digital camera, or a scanned photographic print or slide can be used. For the 3D *resection approach*, the image should not be cropped. The cropped façade image is shown in Figure 3.
2. *Generate the appropriate control points file*, which contains a list of four or more points of known XY coordinates on the reference surface for the 2D approach, or known XYZ coordinates for the 3D approach. The 3D points do not have to be near planar, nor close to the rectification plane ($Z = 0$). Also, the control point coordinates can be either fictitious or real, depending upon the rectification accuracy required. For example, in the case of the image in Figure 2, the nominal dimensions of the carpet could be used. In the façade case we assume that design coordinates are known, or assigned. Example 2D and 3D control point coordinates are shown in Figure 3.

2D Control Points

Label	X	Y	(all co-planar)
4	-8.74	14.74	
6	1.30	26.70	
8	4.77	19.40	
10	6.79	11.86	
12	7.47	4.27	
14	0.00	0.00	

3D Control Points

Label	X	Y	Z	(not necessarily co-planar)
1	0.14	-3.18	9.55	
4	-8.74	14.74	-0.08	
6	1.30	26.70	0.03	
10	6.79	11.86	0.00	
37	-6.64	7.07	-0.46	
38	-6.65	0.35	-0.48	

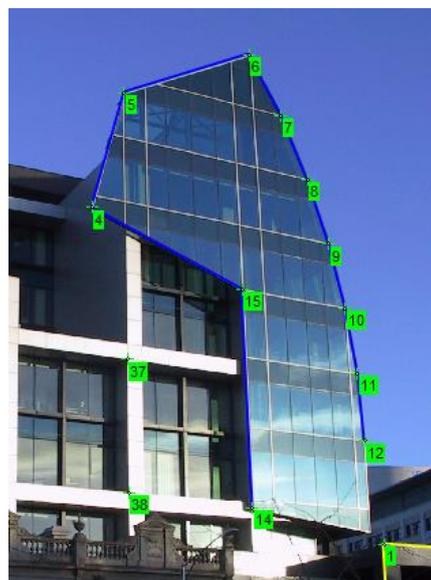


Figure 3. Tilted image to be rectified, along with known 'control' points.

Note: It is very important that the control points be well spread in two dimensions. Ideally, they should ‘enclose’ the planar rectification surface area of interest.

3. Run *XYRectify* (double-click on desktop icon) and import the image or images to be rectified, as well as the file of control points.

To import images, choose either **File|New** from the main **File** pull down menu or **File|Import Images ...** for an existing project. As indicated in Figure 4, select from the Image Browser the folder holding the images. An image in the Select Image(s) list is transferred into the project by first highlighting the image or images and then selecting the ‘>’ button. The ‘>>’ button moves all images into the project. Similarly, the ‘<’ button moves highlighted images out of the project list, and ‘<<’ removes all images.

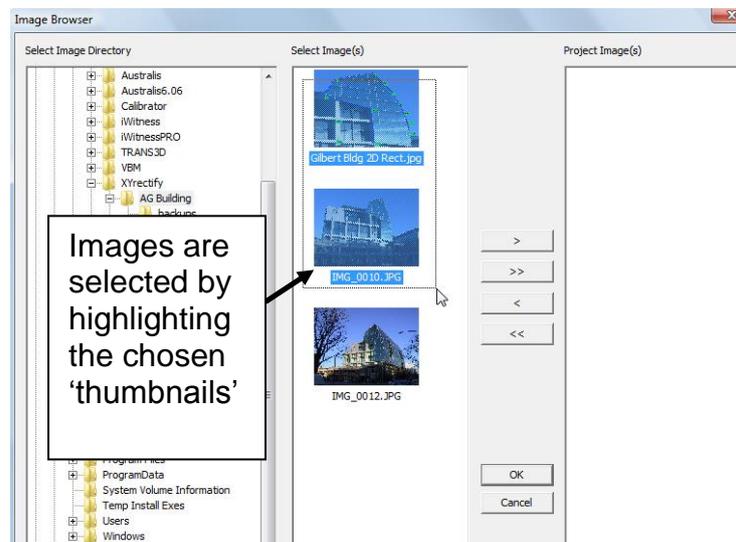


Figure 4. Importing images into the *XYRectify* project.

A single image at a time can be selected, or multiple images can be highlighted by either marquee dragging over the successive images (as shown in Figure 4; left-mouse click and drag) or holding down the CTRL key while selecting multiple images. Holding down the SHIFT key means all images between the two selected images will be selected. Once all are selected, press OK.

4. *Identifying the camera.* *XYRectify* will attempt to identify the camera(s) being used from available *iWitness* and *iWitnessPRO* camera databases. Shown in Figure 5 are the two most common cases: a) where no camera information is available (the top image has been cropped from the one below in this case), and b) where the camera has been used in an *iWitness* project and has calibration data. The calibration data can also be read from an *iWitness* (*.iwp) or *iWitnessPRO* (*.iwpro) project file by selecting the **fill from iwp file** option in the camera dialog.

In instances where it is desired to apply calibration corrections in order to achieve a distortion-free rectified image, the **apply corrections** box should be ticked.

Note also that for the resection (3D) rectification approach, the focal length of the camera must be known. This is not the case for the projective transformation (2D) approach, where a focal length value need not be assigned.

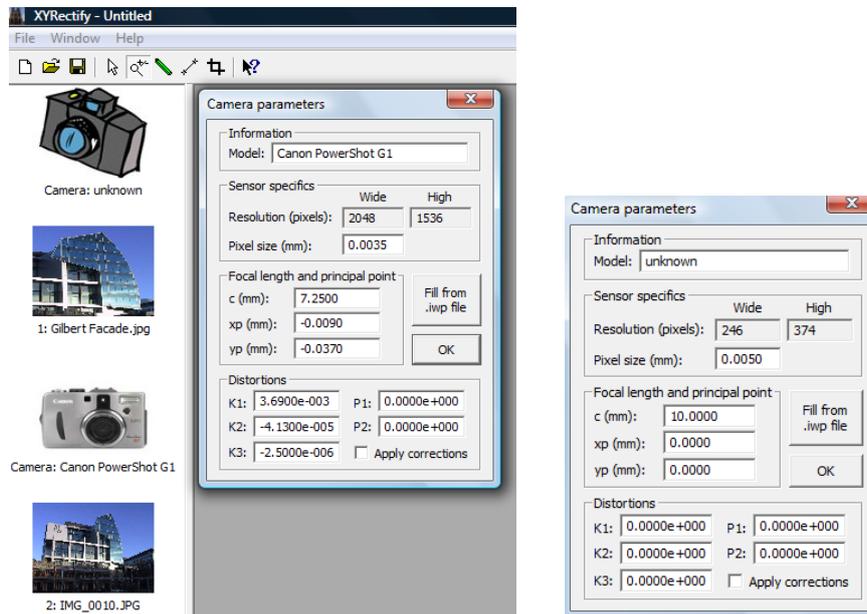


Figure 5. Camera dialog for known, calibrated camera (left) and unknown camera (right).

5. To open an image in the workspace, double-click on its thumbnail.
6. To import the control points file, choose **File/Import Control** and as per Figure 6, choose whether 2D (projective transformation) or 3D (resection approach) control coordinates are to be used. Once the control points file has been loaded, it can be opened for review by double-clicking the icon. Figure 7 shows the workspace with both the image to be rectified and the 3D control points file open. The corresponding 2D control points file for the cropped image is shown in Figure 8.

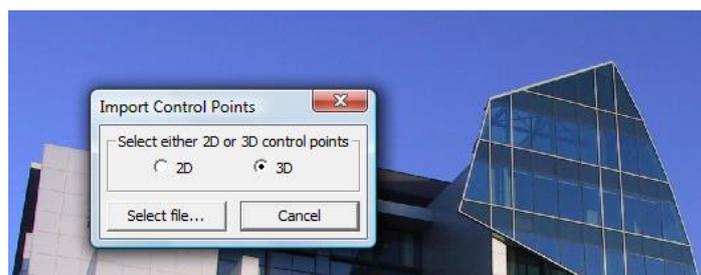


Figure 6. Choose 2D or 3D Control Points.

Note that there can only be one active Control Points file at any given time. If a second file is to be imported, as in this case, the operator needs to select **File/Import Control** again to process the related images.

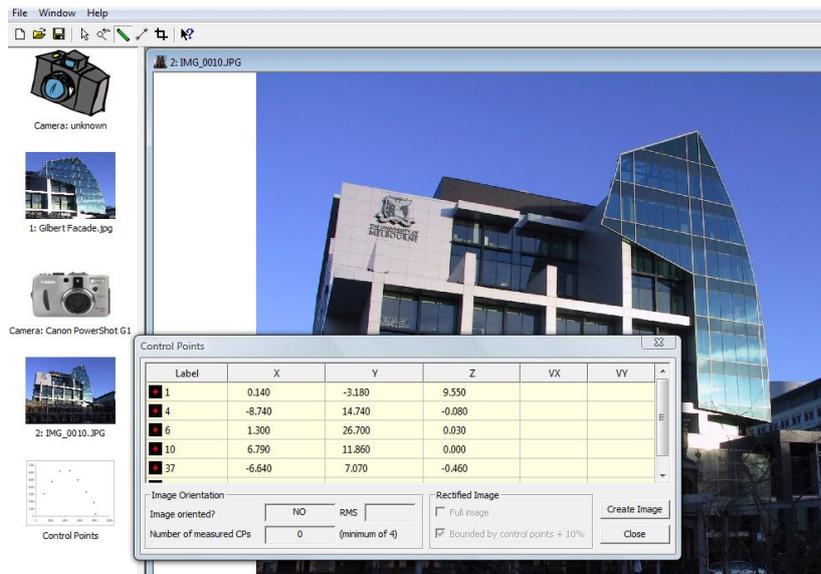


Figure 7. Workspace showing image to be rectified and 3D control points list.

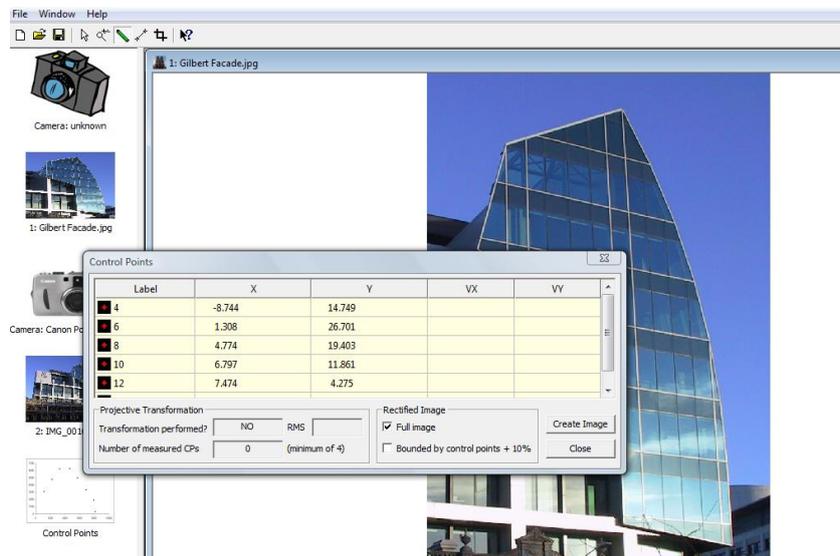


Figure 8. Workspace showing image to be rectified and 2D control points list.

7. *Applying camera calibration corrections.* As mentioned, for higher accuracy rectifications, it is necessary to correct for image distortions, and especially radial lens distortion, in the generation of the rectified image by ticking the **Apply Corrections** box in the camera dialog, as shown in Figure 6.
8. *Roaming, zooming, etc. within an opened image.* Shown in Figure 9 are the hotkeys which can be used within the image view. These come in handy for both marking an image and dealing with cases when there are multiple open images in the workspace.

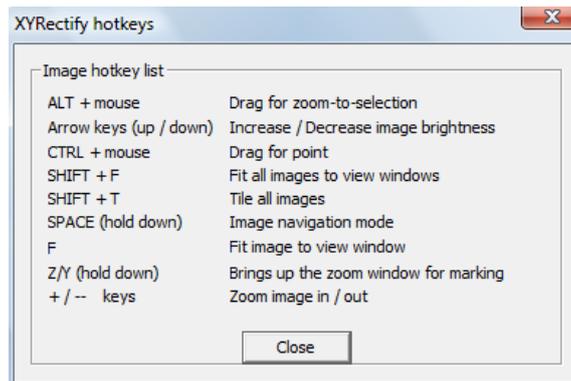


Figure 9. Hotkeys for the image view.

9. Mark the control points in the image so a projective transformation or resection can be performed. Open the image as well as the control points dialog (as in Figure 7). Then, mark the selected points as follows:

i) Click on the control point label in the dialog (the red cross will turn yellow) and then click on the point in the image with the *green pencil cursor* (selectable from the toolbar). The Z-key is very useful for accurate marking. The yellow cross will turn green once the point is marked.

ii) Continue this process until the desired number of control points have been marked. As soon as four are marked, a projective transformation or resection will be performed. Then, as each additional point is marked, the transformation is updated automatically through a least-squares estimation process. Shown in Figure 10 is the case where 5 of 6 available 3D control points have been marked.

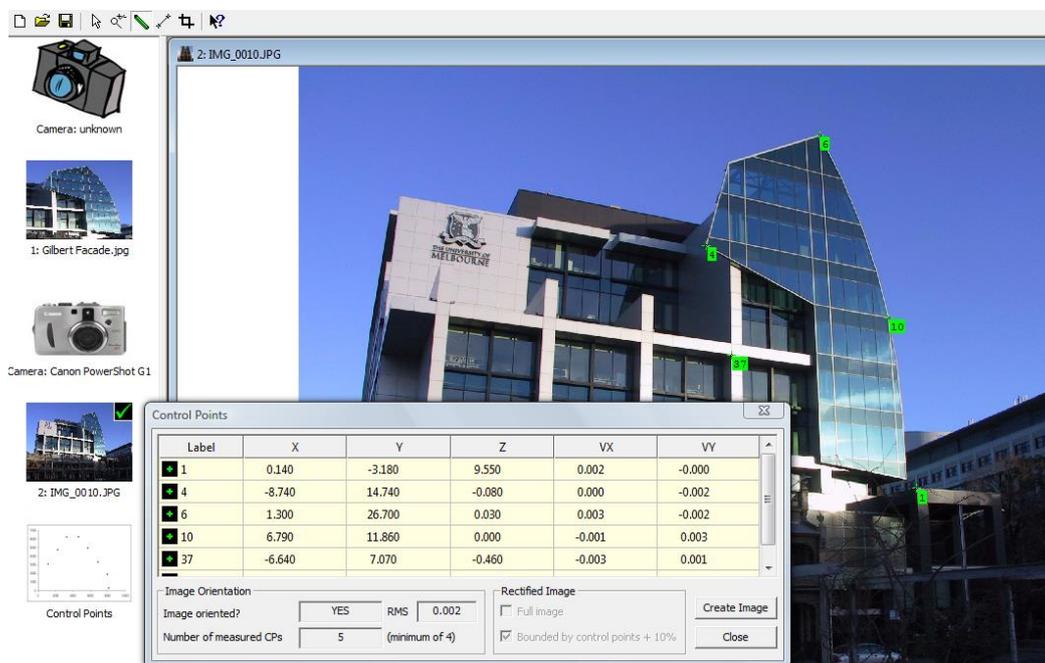


Figure 10. Resection performed with five 3D control points.

The corresponding case for five 2D control points applied to the cropped image is shown in Figure 11.

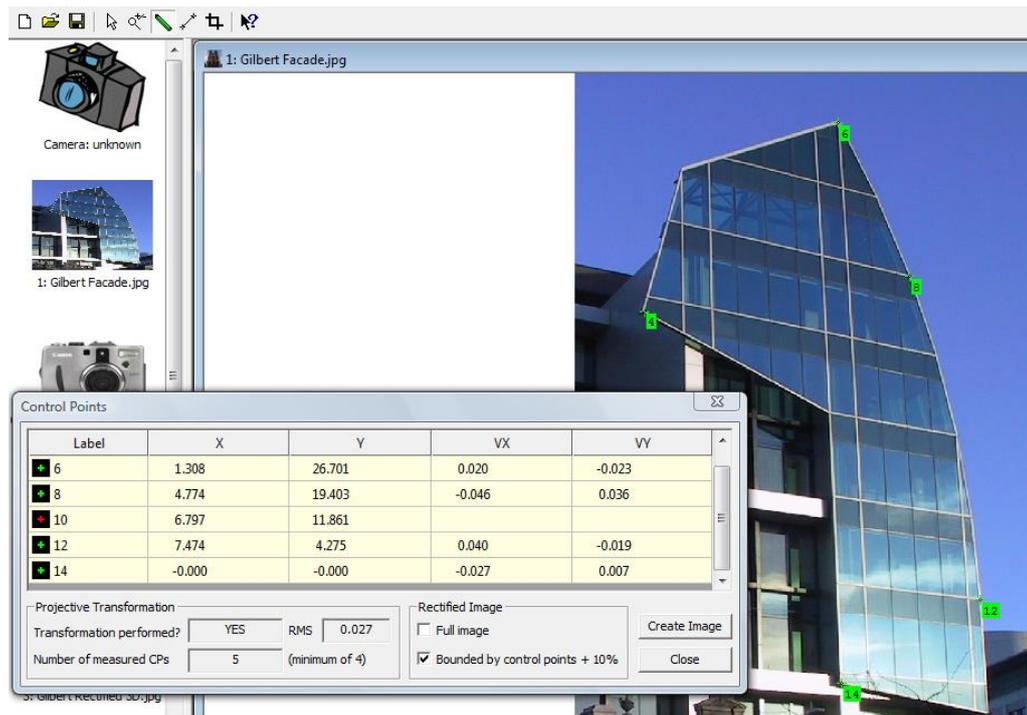


Figure 11. Projective Transformation performed with five 2D control points.

iii) The columns headed VX and VY, and VZ in the 3D case, list the ‘residuals’ from the least-squares adjustment. The root mean square (RMS) value of XY coordinate residuals (in the units of XY) can be used as a quality indicator.

iv) Points can be removed from the transformation process by right-clicking the Point Label in the dialog box and then selecting either *unlink selected point* or *delete selected point*. The transformation computation is automatically updated when a point unlinking or deletion occurs.

10. *Generate the rectified image.* Note in Figure 11 that in the case of the 2D projective transformation the operator can choose to rectify either the entire original image (*full image*), which is the default case, or a portion of the original image (*bounded by control points...*) equal to the area encompassed by the control points, plus a border area of approximately 10%.

Once all desired control points have been marked and the projective transformation or resection results are deemed to be satisfactory, the rectified image can be generated by selecting **Create Image** from the control points dialog box (see Figures 10 & 11). The user is asked for a filename for the transformed image, the thumbnail for which is then added to the icons list. The rectified image can be opened by double-clicking the icon. Figure 12 (right) shows the rectified image (default case of full image) generated from six 2D control points.

11. *Digitizing XY point coordinates in the rectified image.* To digitize XY coordinates in the rectified image, first open the image and then select the green pencil marking tool from the toolbar. As each feature point of interest is marked, its point label (default start label is 1) and X and Y coordinates are written to a list, which can be saved as either a text file or in DXF format.

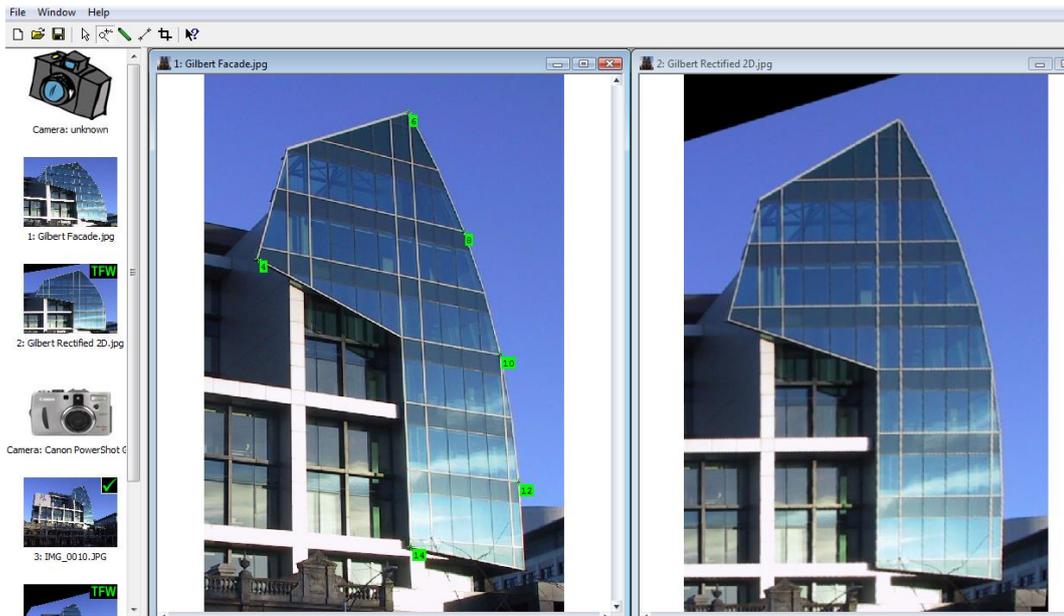


Figure 12. Original image and rectified image generated from six 2D control points.

Any point label can be selected, by choosing the 'L' key and entering the desired alphanumeric label. Subsequent points will use the same label with the last digit being a number that is incremented with each marking. This is illustrated in Figure 13. Note also how the Z key is again useful for precise marking, as indicated in Figure 14.

Note: To delete a digitized point, hold down the CTRL key and drag the cursor over the point or points that are to be deleted. These will turn purple in colour. Then, simply press the delete key.

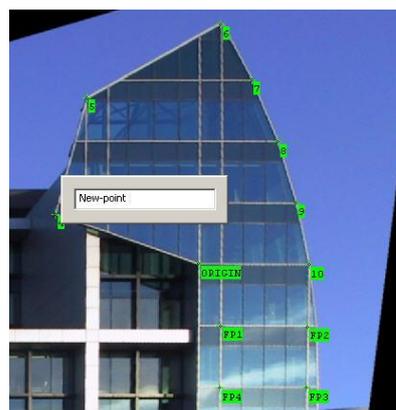


Figure 13. Entering a point label.

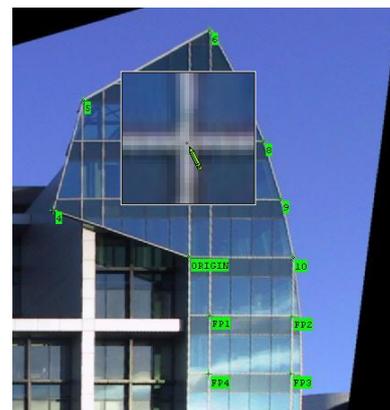


Figure 14. Using the Z-key for precise pointing.

12. *Export coordinate measurements.* Both the observed xy coordinates and the digitized XY coordinates in the rectified image can be exported to either a text file or a DXF file. Right-click on the thumbnail for an image and the menu shown in Figure 15 will appear.

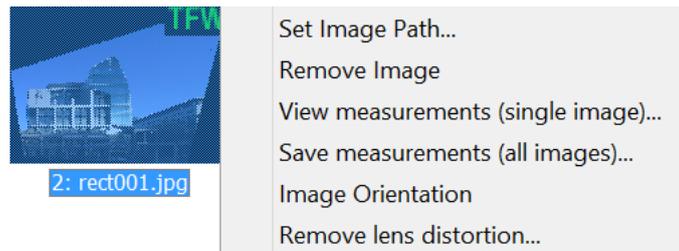


Figure 15. Right-click menu from image thumbnail.

Upon choosing **View Measurements (single image)...**, the coordinate listing will be produced, as shown in Figure 16. The image coordinates (x,y) and the rectified coordinates (X,Y) in the chosen coordinate system are listed.

The parameters in the TFW file can also be listed by selecting **View TFW info**. To create a file of the coordinate data (point label, X, Y), select either the **Export.txt** or **Export.dxf** buttons and specify the file name. The **imagename.TFW** file, which is saved to the project folder, is in ASCII format and can be opened, for example, with NotePad or TextPad. The TFW file contains 6 numbers: Line 1 – X-scale, Line 2 – rotation about Y, Line 3 – rotation about X, Line 4 – Y-scale, Lines 5 and 6: X and Y coordinates, respectively, of the top left pixel.

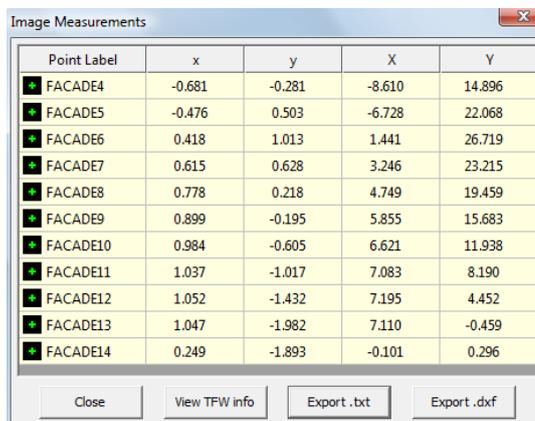
The **Save Measurements (all images)...** menu selection allows the user to output the (x,y) and (X,Y) coordinates for all of the rectified images within the project. This is very beneficial in applications such as deformation or displacement monitoring where there are multiple images within a project. The **Save Measurements (all images)...** command will output all (X,Y) coordinates of digitised points for each rectified image in the same file, in the same coordinate system. Point displacements and deformation can then be quantified by simple coordinate differencing between the feature points digitised in successive rectified images.

The image (x,y) coordinates of the control points can also be exported by selecting **Measurements...** after right-clicking on the thumbnail of the unrectified image.

The right-click menu can also be accessed to:

- i) To re-link images to the current project, where the project file has been moved between either directories or different computers, use the **Set Image Path** option.
- ii) Remove an image from the project (the file is not deleted from the directory) via **Remove Image**.
- iii) List the **Image Orientation** parameters in the case of the resection solution.
- iv) Generate a distortion-free image from the original image. This **Remove Lens Distortion** creates an image of the same size as the input image that has been corrected for pin cushion and barrel radial distortion in accordance with the camera calibration parameters provided. Corrections for x_p, y_p are not applied; these are temporarily set to zero for this operation in order to avoid a potentially annoying shift in the corrected image.

13. *Cropping the Rectified Image.* It is possible to ‘cut out’ and save a rectangular portion of the rectified image. This cropping feature is invoked by selecting the *Cropping Button* (see Figure 17) on the toolbar, and then marquee dragging the Select cursor to define the rectangle bounding the new image. The ‘cut out’ section of the rectified image is then saved as a JPEG with a TFW file to enable direct XY coordinate digitizing, in the same way as with the original rectified image. The cropping process is illustrated in Figure 17.
14. *Drawing lines between points in the rectified image.* As an aid in marking objects within the rectified image, it is possible to draw lines between digitised points, as indicated in Figure 18. These lines can also be exported via the *Export DXF* option in the image measurements dialog. To draw lines, simply select the *Line Tool* (Figure 18) and click the points to be joined.



Point Label	x	y	X	Y
FACADE4	-0.681	-0.281	-8.610	14.896
FACADE5	-0.476	0.503	-6.728	22.068
FACADE6	0.418	1.013	1.441	26.719
FACADE7	0.615	0.628	3.246	23.215
FACADE8	0.778	0.218	4.749	19.459
FACADE9	0.899	-0.195	5.855	15.683
FACADE10	0.984	-0.605	6.621	11.938
FACADE11	1.037	-1.017	7.083	8.190
FACADE12	1.052	-1.432	7.195	4.452
FACADE13	1.047	-1.982	7.110	-0.459
FACADE14	0.249	-1.893	-0.101	0.296

Figure 16. Listing of digitized coordinates.

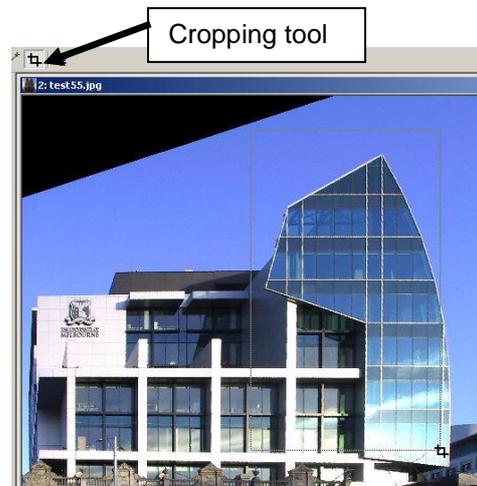


Figure 17. Cropping the rectified image

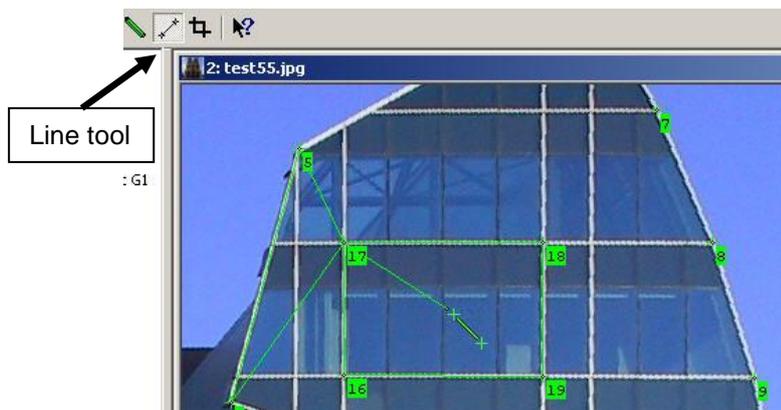


Figure 18. Drawing lines

15. *Saving the project.* Finally, the project should be saved via *File|Save* or *File|Save as...* or by using the save toolbar button. The project (*filename.xyr*) can subsequently be re-opened to the same stage at which it was saved.