

## 6.4 Geometric corrections and image referencing

Remote sensing data is affected by geometric distortions due to sensor geometry, scanner and platform instabilities, earth rotation, earth curvature, etc. Some of these distortions are corrected by the image supplier and others can be corrected referencing the images to existing maps.

Remotely sensed images in raw format contain no reference to the location of the data. In order to integrate these data with other data in a GIS, it is necessary to correct and adapt them geometrically, so that they have comparable resolution and projections as the other data sets.

The geometry of a satellite image can be distorted with respect to a North-South oriented map:

- Heading of the satellite orbit at a given position on Earth (rotation).
- Change in resolution of the input image (scaling).
- Difference in position of the image and map (shift).
- Skew caused by earth rotation (shear).

The different distortions of the image geometry are not realized in certain sequence, but happen all together and, therefore, can not be corrected step wise. The correction of all distortions at once, is executed by a transformation which combines all the separate corrections. The transformation most frequently used to correct satellite images, is a first order transformation also called affine transformation. This transformation can be given by the following polynomials:

$$X = a_0 + a_1 r_n + a_2 c_n$$


$$Y = b_0 + b_1 r_n + b_2 c_n$$

where:

$r_n$  is row number,  $c_n$  is column number,  $X$  and  $Y$  are map coordinates.

To define the transformation, it will be necessary to compute the coefficients of the polynomials (e.g.  $a_0$ ,  $a_1$  and  $a_2$ ). For the computations, a number of points have to be selected that can be located accurately on the map ( $X$ ,  $Y$ ) and which are also identifiable in the image (`row`, `column`). The minimum number of points required for the computation of coefficients for an affine transform is three, but in practice you need more. By selecting more points than required, this additional data is used to get the optimal transformation with the smallest overall positional error in the selected points. These errors will appear because of poor positioning of the mouse pointer in an image and by inaccurate measurement of coordinates in a map. The overall accuracy of the transformation is indicated by the average of the errors in the reference points: The so-called *Root Mean Square Error* (RMSE) or *Sigma*.

If the accuracy of the transformation is acceptable, then the transformation is linked with the image and a reference can be made for each pixel to the given coordinate system, so the image is geo-referenced. After geo-referencing, the image still has its original geometry and the pixels have their initial position in the image, with respect to row and column indices.

In case the image should be combined with data in another coordinate system or georeference, then a transformation has to be applied. This results in a  new image where the pixels are stored in a new line/column geometry which is related to the other georeference (containing information on the coordinates and pixel size). This new image is created by means of *resampling*, by applying an interpolation method. The interpolation method is used to compute the radiometric values of the pixels, in the new image based on the DN values in the original image.

After this action, the new image is called *geo-coded* and it can be overlaid with data having the same coordinate system.

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! In case of satellite imagery from optical systems, it is advised to use a linear transformation. Higher order transformations need much more computation time and in many cases they will enlarge errors. The reference points should be well distributed over the image to minimize the overall error. A good choice is a pattern where the points are along the borders of the image and a few in the center.

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### 6.4.1 Geo-referencing using corner coordinates

When an image (raster map) is created, either by a satellite, airborne scanner or by an office scanner, the image is stored in row and column geometry in raster format. There is no relationship between the rows/columns and real world coordinates (UTM, geographic coordinates, or any other reference map projection). In a process called *geo-referencing* the relation between row and column number and real world coordinates are established.

In general, two approaches can be followed:

- *Georeference corners*: Specifying the coordinates of the lower left and upper right corner of the raster image plus the actual pixel size in case these are known (see figure 6.7).
- *Georeference Tiepoints*: Specifying reference points that relate for distinct points their row/column number with the corresponding X/Y coordinate.

In this exercise the first method of corner coordinates and the pixel size will be used. When the X and Y coordinates of the corners of the raster image and the pixel size are known, it is possible to derive a mathematical equation that relates the row and column numbers to X and Y coordinates. The original arrangement of the pixels is still intact and no resampling has taken place.

In this exercise, the raster map that will be used consists of a scanned topographic map of an area in the Flevo polder (the Netherlands). There are two version of this map: One called *Topomap* which will be used in this exercise, and another one, called *Polder*, which will be used in the remainder of the exercises on

georeferencing. Also the analog map of the same area is used (see figure 6.8). The scanned image shows a part of the Flevo polder near Vollenhove.

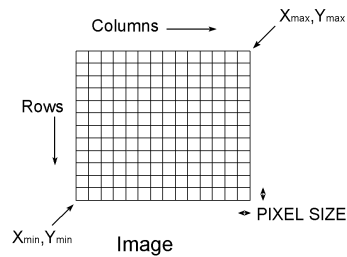


Figure 6.7: The principle of Georeference corners. The coordinates are defined by the coordinates of the corners and the pixel size



- Display the scanned topographic map (Topomap) and zoom in to see the detail. As you can see this map is not very detailed.
- Move through the map with the mouse pointer and note that on the Status line of the map window the row and column location (RowCol) of the mouse pointer is shown, and the message “No Coordinates”. The image is not geo-referenced.

When there is a link between a raster map and a *georeference*, we are able to know the real world coordinates of each pixel. The georeference object was already discussed in chapter 2. It contains information on the relation between row and column positions and the real world coordinates. The same *georeference* file is normally used for all raster maps of the same area that you want to combine in a certain analysis. All images or maps that have the same amount of rows and columns, the same pixel size, and that cover the same area, should use the same *georeference*.



- Open the Create GeoReference dialog box by selecting New GeoRef in the Operations-list. The Create GeoReference dialog box is opened.
- Enter Flevo for the GeoReference Name. Note that the option GeoRef Corners is selected.
- Type: GeoReference for the Flevo Polder in the text box Description.
- Click the Create button next to the list box Coordinate system. The Create CoordSystem dialog box is opened.

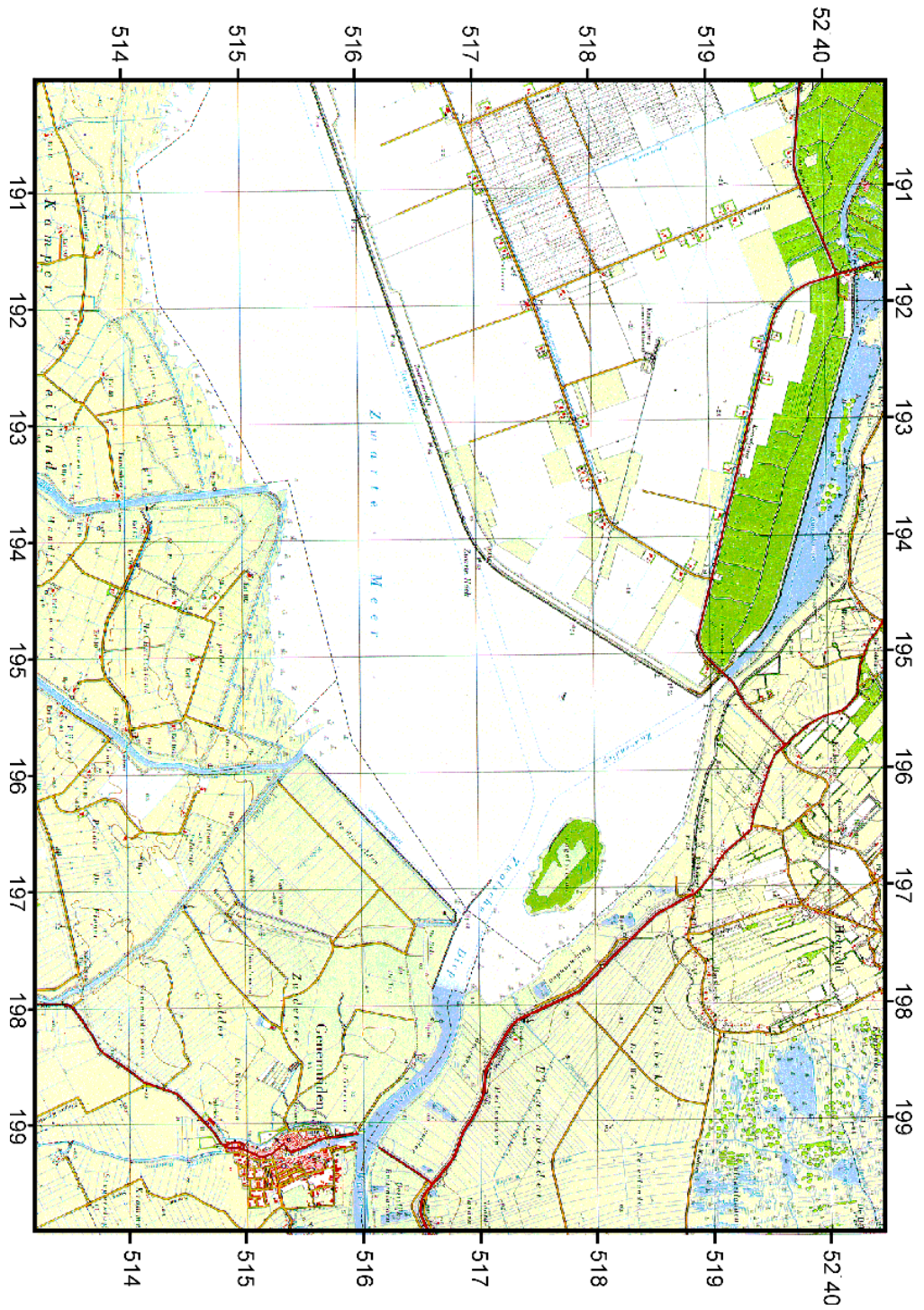


Figure 6.8: The topomap of the Flevo Polder (The Netherlands) used in this exercise

As mentioned in chapter 2, a *Georeference* is linked to a *Coordinate system*, which contains the minimum and maximum coordinates of the study area, and the projection parameters. It is always advised to create a *Coordinate system* for the study area where you are working, even if you do not have information on the projection, instead of using the coordinate system *Unknown*. This is important if you want to transform later, other data that have different coordinate systems and/or projections.



- Type **Flevo** for the **Coordinate System Name**.
- Type: **Coordinate system for the Flevo Polder** in the text box **Description**. Click **OK**. The **Edit Coordinate System** dialog box is opened.
- Type the following coordinates for **Min X, Y: 180000 and 500000**, and for **Max X, Y: 210000 and 550000**. The projection will not be defined now. Click **OK**. Now you are back in the **Create Georeference** dialog box.
- Enter for the **Pixel size: 10 (meters)**.
- Type the following coordinates for **Min X, Y: 191000 and 514000**, and for **Max X, Y: 199000 and 519000**.
- Clear the check box **Switch Center of Corner Pixels**.

The entered values for the X and Y coordinates, indicate the extreme corners of the lower left and upper right pixels and not the center of these pixels. An indication whether the entered data is correct, is the display of the number of rows and columns of the image (500 lines and 800 columns).



- Accept the other defaults and click **OK**.

In order to establish a link between the map **Topomap** and its georeference **Flevo**, the **Properties** of the map **Topomap** have to be edited.



- Click the map **Topomap** with the right mouse button and select **Properties** from the context-sensitive menu. The **Properties** dialog box is opened.
- In the **Properties** dialog box, press the **Edit Properties** button. As you can see the Georeference is **None**. Select the Georeference **Flevo**. Click **OK**.
- Click **OK** in the **Properties** dialog box.

- Display the map `Topomap` and check whether the map now has coordinates.
- Move around in the map and determine for some pixels located on the grid system the accuracy of the transformation. Use the zooming option if necessary. Also conduct some measurement. The distance between the gridlines is 1000 meters.
- Close the map window when finished.

### 6.4.2 Geo-referencing a raster image using reference points

In the previous exercise, you have seen how you can georeference a map by specifying the coordinates of the lower left and upper right corner of the image, plus the actual pixel size (Georef Corners). In many cases, you do not know the X/Y coordinates of the corners of the map or image. You only know the coordinates for some points in the image. In this case georeferencing will be done by specifying reference points (tiepoints) that relate for distinct points their row/column number with the corresponding X/Y coordinate (figure 6.9).

For a number of points that can be clearly identified, both in the image as on a topographic map, the coordinates are determined. Reference points have to be carefully selected. Corresponding locations of objects in the image and on a map, have to be carefully addressed and measured, especially when there is a large time difference between the production of the map and the acquisition date of the image. Examples of good reference points are highway intersections, fixed river crossings (bridges), railway crossings, runways/ airports, etc.

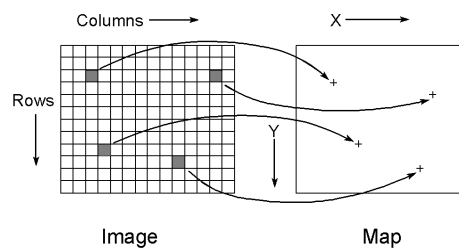


Figure 6.9: Geo referencing using reference points or Tiepoints

The entered reference points are used to derive a polynomial transformation of the first (affine), second or third order. Each transformation requires a minimum number of reference points (3 for affine, 6 for second order and 9 for third order

polynomials). In case more points are selected, the residuals and the derived *Root Mean Square Error* (RMSE) or *Sigma*, may be used to evaluate the calculated equations.

After geo referencing, each time a pixel is addressed in the display window the corresponding X,Y coordinate is returned. Note that the scanned image is not actually transformed. The original arrangement of the pixels is still intact and no resampling has taken place.

The image used in this exercise is a SPOT-XS band 3 satellite image of an area near Vollenhove (the Netherlands): `Spotb3`. An analog topographic map of the same area is also used: `Polder` (see figure 6.8). The scanned image shows an area of the new polder area, called Flevo polder, a lake and the so-called old land in the surroundings of the village of Vollenhove. First the topomap will be georeferenced.



- Display the map `Polder`.
- Move through the image with the mouse pointer and note that the image is not georeferenced (No Coordinates are displayed on the Status line).

Study the coordinate systems on the analog topo sheet.

The Geo Reference is going to be created using reference points. The selection of the *reference points* (in ILWIS also called *Tiepoints* or *Ground Control Points*) are made on a reference map.



- In the map window, open the File menu and select **Create, Create GeoReference**. The Create Georeference dialog box is opened.
- Enter `Flevo2` for the **GeoReference Name**.
- Type: `GeoReference` for the Flevo Polder in the text box **Description**.
- Click on the option **Georef Tiepoints**.
- Select the **Coordinate system** `Flevo` (the one you created in the previous exercise).
- Select the **Background Map**: `Polder`.
- Click **OK**.

The **GeoReference Editor** is opened. It consists of a map window, in which you will see the mouse pointer as a pencil, and a table with the columns `X`, `Y`, `Row`, `Column`, `Active`, `DRow`, `Dcol`.



- Zoom in on a point where horizontal and vertical gridlines intersect (for example: P4: x=191000 and y=514000).
- Locate the mouse pointer (pencil) exactly at the intersection and click. Enter in the **Add Tiepoint** dialog box the correct X and Y coordinate values.
- Repeat this procedure for at least 3 more points. For example, use the following points:  
P1 (x =191000, y= 519000), P2 (x=199000, y=519000), P3 (x = 199000, y= 514000).

When four control points are entered, a sigma and residuals (Drow and Dcol) are calculated. If you used the four suggested points, and located the row and columns exactly, the sigma should be around 1.

The overall sigma value indicates the accuracy of the transformation. To determine the accuracy in meters, the obtained sigma value should be multiplied by the pixel size.



- Close the **Tiepoint Editor** and the map window.

Now that the topographic map Polder is georeferenced, you can use it to georeference the Spot images of the region.



- Open the **Create GeoReference** dialog box by selecting **NewGeoref** in the Operations-list. The **Create Georeference** dialog box is opened.
- Enter **Flevo3** for the **GeoReference Name**.
- Type: **GeoReference** for the **Flevo Polder** in the text box **Description**.
- Select the option **GeoRef Tiepoints**.
- Select the **Coordinate system Flevo** (the one you created in the previous exercise).
- Select the **Background map: Spotb3**. Click **OK**.
- The **Display Options** dialog box is opened. Click **OK**.



The **GeoReference Editor** is opened. It consists of a map window, in which you see the mouse pointer as a pencil, and a table with the columns *X*, *Y*, *Row*, *Column*, *Active*, *DRow*, *DCol*.

At this point you can start entering the reference points (tiepoints), by entering the *X* and *Y* coordinates (real world coordinates on the topo map) and the row and column numbers in the image.

In the **Georeference Tiepoints Editor**, you can add tiepoints to a map in several manners:

- Firstly, click with the pencil shaped mouse pointer at a recognizable point in the background map without coordinates. The **Add Tiepoint** dialog box appears. In this dialog box, the row and column values at the position of the click are entered. When already sufficient tiepoints are selected, the dialog box will come up with a suggestion for the *XY* coordinates.

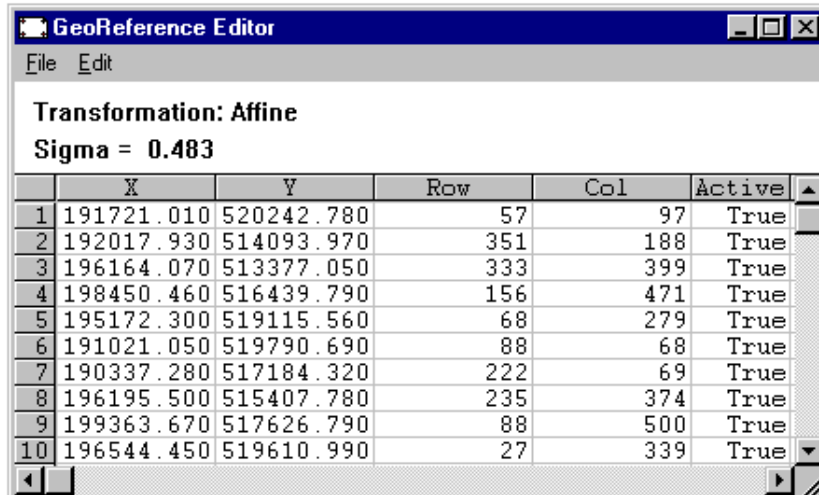
Then:

- Click at the same position in a map of the same area which is already georeferenced and which is displayed in another map window (in this case the map *Polder*), or;
- Digitize the same point in an analog paper map which is stuck on a digitizer, or;
- Read the correct *XY* coordinates for this point from an analog paper map (figure 6.8) or a table, and type these *XY* coordinates in the dialog box.



- Select locations on the image of which you can find coordinate pairs on the analog map (figure 6.8). You may also use the map *Polder*, which is a digital version of figure 6.8.
- Zoom in on a chosen location and use the mouse pointer (in the shape of a pencil), to select as accurate as possible the reference point in the map window.
- Enter in the **Add Tie Point** dialog box the correct *X* and *Y* coordinate values, taken from the analog map sheet, or the digital map *Polder*.
- Repeat this procedure for at least 10 points. You may select your own points, or use the ones that are listed in table 6.10.

If you would use the control points as given in figure 6.10, the sigma in the **GeoReference Editor** will be equal as in this example. By default an affine transformation is used. This can be changed by selecting one of the other transformations.



	X	Y	Row	Col	Active
1	191721.010	520242.780	57	97	True
2	192017.930	514093.970	351	188	True
3	196164.070	513377.050	333	399	True
4	198450.460	516439.790	156	471	True
5	195172.300	519115.560	68	279	True
6	191021.050	519790.690	88	68	True
7	190337.280	517184.320	222	69	True
8	196195.500	515407.780	235	374	True
9	199363.670	517626.790	88	500	True
10	196544.450	519610.990	27	339	True

Figure 6.10: Result example of the Tiepoints in the GeoReference Editor

As the number of control points is larger than needed to compute the transformation formula, a sigma and residuals (DRow and DCol) are calculated. The overall sigma value indicates the accuracy of the transformation. To determine the accuracy in meters, the obtained sigma value should be multiplied by the pixel size.

The DRow and DCol values indicate the accuracy of each individual tiepoint according to the transformation formula (in pixel units).

A tiepoint can be selected or excluded from the transformation computation by putting True or False respectively in the column Active.

The tiepoints that are excluded can be used to evaluate the transformation performance (under the conditions that these tiepoints are correctly chosen).

A tiepoint can be deleted by clicking its record number and by selecting Edit, Delete Tiepoint, or by pressing <Delete> on the keyboard. If confirmed, the tiepoint will be deleted.

Based on the expected geometric distortions in the background image a transformation is selected. A number of possible transformation is given in Edit, Transformation.



- While moving with the cursor over the image with the marked tiepoints, press the right mouse button to display the context-sensitive menu.
- Select Transformation in order to open the Transformation dialog box.

- Six different transformation are shown. The `Affine` transformation is given by default. Click `OK` to accept it. A sigma value and the residuals are shown.
- Leave the `GeoReference` editor by clicking the right mouse button and selecting `Exit Editor`.
- The image `Spotb3` now has coordinates. Check this. Move around in the image and determine for some easy identifiable pixels the accuracy of the transformation. Use the zooming option if necessary.
- Click `Spotb1` with the right mouse button and select `Properties`. Change the georeference of the image `Spotb1` to `Flevo3`. Close the `Properties` dialog box.
- Do the same for `Spotb2`.
- Close all map, table and pixel information windows (if necessary) when the exercise is finished.

Now all the three SPOT bands are georeferenced.

### 6.4.3 Geo-coding a raster image by resampling

After geo-referencing an image, the image will have coordinates for each pixel, but its geometry is not corrected for geometric distortions and not adapted to a master map or image. To create a distortion free adapted image, the transformation that is defined during geo referencing (see previous exercise) is executed. This process, geo-coding, results in a new image in which the pixels are arranged in the geometry of the master image or map, and the resolution is equal to the resolution of the master image or chosen in case the master is a topographic map. The radiometric values or pixels values of the new image are found by resampling the original image using a chosen interpolation method (figure 6.11).

The value for a pixel in the output image is found at a certain position in the input image. This position is computed using the inverse of the transformation that is defined in the geo-referencing process.

Whether one pixel value in the input image, or a number of pixel values in that image are used to compute the output pixel value, depends on the choice of the interpolation method.

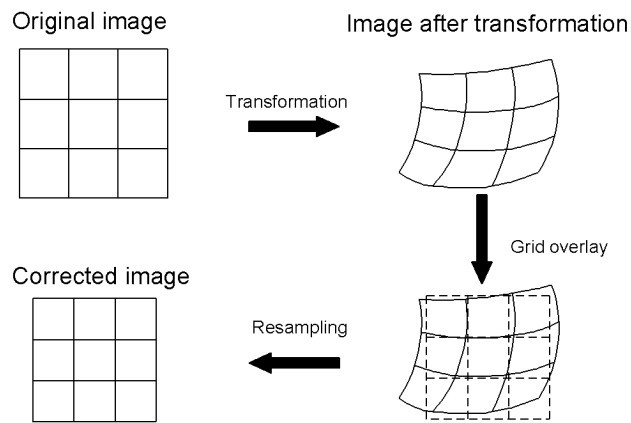


Figure 6.11: The process of geo-coding

There are three different interpolation methods:

- **Nearest neighbor.** In the nearest neighbor method, the value for a pixel in the output image is determined by the value of the nearest pixel in the input image.(figure 6.12 a).
- **Bi-linear.** The bi-linear interpolation technique is based on a distance dependent weighted average, of the values of the four nearest pixels in the input image (figure 6.12 b).
- **Cubic convolution.** The cubic convolution or bi-cubic uses the sixteen surrounding pixels in the input image.

The image used in this exercise is a SPOT XS band 3 image: `Spotb3` and the corresponding georeference file: `Flev02`. The analog topomap is also used.



- Display the satellite image (`Spotb3`) and the digital topomap (`Topomap`). Position the two map windows next to each other.
- Compare the geometry of the image with the topographic map (figure 6.8) and file `Topomap`. Indicate with a drawing how the image should be rotated in order to fit the map. Sketch the rotation of the SPOT XS image compared to the topographic map sheet.
- Close the map windows when finished.

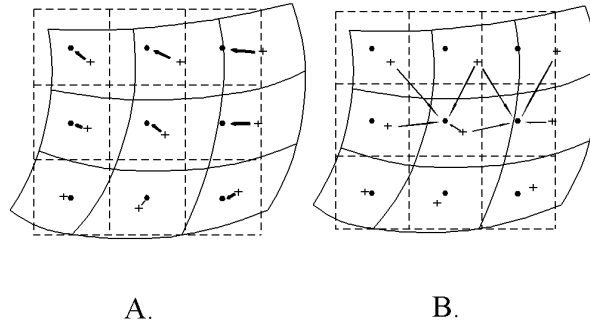


Figure 6.12: Interpolation methods. A: Nearest Neighbor, B: Bi-linear interpolation

For the following activity a georeference file of the image should exist. If not, go to the previous exercise.

To transform the input image into the required geometry, it needs to be resampled.



- Georeference the image `Spotb3` if you haven't done that yet. See previous exercise.
- Select **Resample** in the Operations-list in order to display the **Resample Map** dialog box.
- Enter `Spotb3` for **Raster Map**, select the resampling method **Nearest Neighbor**.
- Type `Spotb3r` as **Output Raster Map name**.
- Select the **GeoReference** for the output map (`F1evo`). Select the option **Show**. Type: `Resampled Spot Band 3` for **Description**. Click **OK**.

The resampling now takes place. After finishing, the **Display Options** dialog box is opened.



- Click **OK** in the **Display Options** dialog box. The map is displayed.
- Move around in the image and determine for some easy identifiable pixels the accuracy of the transformation. Use the zooming option if necessary.
- Close the map window when the exercise is finished.

## 6.4.4 Image-to-image registration

Accurate topographic maps are often not available to perform a standard geometric correction or georeferencing. In order to combine images of different dates and/or from different sensor systems, an *image-to-image registration* is executed. In an image-to-image registration, the distortions are not removed and no referencing to a coordinate system is needed. In image registration, one image is selected as reference and another image is matched to that one. The base image is often referred to as *Master image* and the other one is called the *Slave image*. The slave image is resampled to the master image. This requires the availability of objects identifiable on both images (figure 6.13).

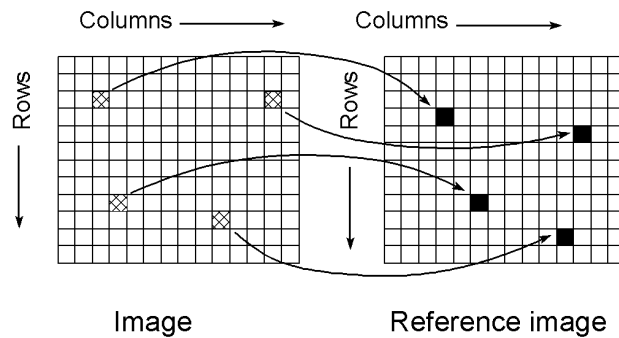


Figure 6.13: Image to image registration

The registration operation does not imply correcting any geometric errors inherent in the images, since geometric errors are immaterial in many applications e.g. change detection. For referencing an image to any geometric system, *tiepoints* are needed. These points should not be named ground control points or geo-reference points, since no relation is specified between the selected point and a location expressed in any map projection system. However, the master image has to be linked in an earlier process to a reference system. The slave image will inherit this reference system after registration. The definition of the transformation used for the registration and the resampling is further identical to the geo-referencing. The transformation links the row/column geometry of the slave to the row/column geometry of the master.

To make the image-to-image registration, a SPOT band 3 and an ERS1 image of the Flevo polder in the Netherlands are used:

SPOT Band 3, Aug. 1995: Master

ERS1 Aug 1995: Slave

The georeference for the master image was created in a previous exercise. This image, now with coordinates, can be used to reference the slave image to the same geometry.



- Display the map `Spotb3`.

The slave image is to be registered on the master image using *tiepoints*. The procedure is practically the same as in the exercise “Georeferencing a raster image using reference points”.



- Create a new Georeference (i.e. `Flevoers`) for the slave image (method to be used: `GeoRef Tiepoints`, background map `Ers1`).
- Open the **GeoReference Editor**.
- Display simultaneously the master image (`Spotb3`), the slave image (`Ers1`) and the **GeoReference Editor**. If necessary, resize and/or reposition the open windows.
- Select first a tiepoint in the slave image and click on the left mouse button (the row/column number appears in the **Add Tie Point** dialog box).
- Move to the map window with the master image. Select the same tiepoint and click the left mouse button. The corresponding X,Y coordinates are displayed in the **Add Tie Point** dialog box.
- Enter a minimum of 5 control points.
- Resample the slave map using the **Nearest Neighbor** resampling method. Use as Output Raster Map name `Ers1c`.
- Display `Ers1c` and `Spotb3r`.
- Compare the resampled `Spotb3` and the resampled `Ers1`.
- Close all map windows.

### Summary: Geometric corrections and image referencing

- Remote sensing data is affected by geometric distortions due to sensor geometry, scanner and platform instabilities, earth rotation, earth curvature, etc.
- Remotely sensed images in raw format contain no reference to the location of the data. In order to integrate these data with other data in a GIS, it is necessary to correct and adapt them geometrically, so that they have comparable resolution and projections as the other data sets.

- The correction of all distortions at once, is executed by a transformation which combines all the separate corrections. The transformation most frequently used to correct satellite images, is a first order transformation also called *affine transformation*.
- To define the transformation, it will be necessary to compute the coefficients of the polynomials. For the computations, a number of points have to be selected that can be located accurately on the map (X, Y) and which are also identifiable in the image (row, column).
- The overall accuracy of the transformation is indicated by the average of the errors in the reference points: The so-called *Root Mean Square Error* (RMSE) or *Sigma*.
- After geo-referencing, the image still has its original geometry and the pixels have their initial position in the image, with respect to row and column indices.
- In case the image should be combined with data in another coordinate system or georeference, then a transformation has to be applied. This results in a new image where the pixels are stored in a new line/column geometry which is related to the other georeference. This new image is created by means of *resampling*, by applying an interpolation method. The interpolation method is used to compute the radiometric values of the pixels, in the new image based on the DN values in the original image.
- After this action, the new image is called *geo-coded* and it can be overlaid with data having the same coordinate system.