# 3: GEOMETRIC CORRECTION OF AN AERIAL IMAGE OF SOUTH CAICOS ISLAND

## Aim of Lesson

To learn how to rectify an image to a Universal Transverse Mercator (UTM) coordinate system and to understand why it is important to carry out geometric correction of remotely sensed images.

## Objectives

1. To understand that measurements made from images that have not been geometrically corrected can be misleading and that just because an image looks like a map it does not necessarily have the properties of a map.

2. To learn how to make measurements of distances between points on an image using Pythagoras's theorem so that you can compare distances between known points *before* and *after* rectification and georeferencing of the image.

3. To discover how Ground Control Points (GCPs) are obtained at selected positions, which are carefully chosen to be readily identifiable on the image, using a Global Positioning System (GPS) so that the geographical coordinates of a series of pixels can be linked together in a rectification table.

4. To understand how a rectification table works by linking pixels at know column and row coordinates to GCPs at know geographical (in this case-study, Universal Transverse Mercator) coordinates obtained using a GPS.

5. To use *Bilko* to enter details of three GCPs in the rectification table and learn how to select an appropriate transformation (linear, quadratic or cubic) for rectification.

6. To understand what Root Mean Square (RMS) error means and find out how to deselect problem GCPs that have unacceptably high RMS errors (perhaps due to a GPS error or human error in transcribing coordinates).

7. To carry out rectification and resampling of the image to the Universal Transverse Mercator (UTM) grid system of local maps of the Turks & Caicos Islands.

8. To compare measurements between points on the geometrically corrected and uncorrected images and see how much positional error may result from using uncorrected imagery.

## Background Information

This lesson relates to material covered in Chapter 6 of the *Remote Sensing Handbook for Tropical Coastal Management* and you are recommended to consult this or a range of other remote sensing texts (e.g., Mather, 1999; Wilkie and Finn, 1996; ERDAS, 1994) for further details of the theory and techniques of geometric correction.

### The *Bilko 3* image processing software

Familiarity with *Bilko 3* is required to carry out this lesson. In particular, you will need experience of using Transects and **Edit, Go To** to find out distances between points. A familiarity with switching geographical coordinates on and off using the **View, Coords** feature, connecting images using **Image, Connect**, and with the *Excel* spreadsheet package is also desirable. Tutorials 2, 3, 7 and the

first part of Tutorial 8 in the *Introduction to using Bilko* are particularly relevant and provide a good grounding for this lesson.

## Image data

For this lesson, you are presented with part of a scanned black and white aerial photograph of South Caicos Island, which, you are told, was taken in 1981. You want to use this image to look at how parts of the island have changed and thus need to geometrically correct it and georeference it to the local map, which uses Universal Transverse Mercator (UTM grid zone 19 N) coordinates, so that you can compare it with other similarly georeferenced images taken at later dates. The local maps (Ordnance Survey map Series E8112 DOS 309P) also use the Clarke 1866 spheroid and NAD (North American Datum) 27 (Bahamas) datum. A spheroid tries to account for the fact that the Earth is not a sphere but an oblate spheroid. The Clarke 1866 spheroid is appropriate for and often used in North and Central America and the Caribbean. A geodetic datum is a smooth mathematical surface that closely fits the mean sea-level surface in a specific area of interest. The NAD 27 (Bahamas) datum is appropriate for the Bahamas (except San Salvador Island) and the Turks & Caicos Islands. For further details of the UTM Grid System, spheroids and datums, a useful reference is Butler *et al*. (1987).

You are not quite sure whether the image was taken professionally or is a near vertical with significant distortion. You are told that the image was scanned so that the pixel size is approximately 3.5 m x 3.5 m but want to check this.

## Field survey data

In order to carry out geometric correction we have looked for obvious points visible on the aerial photograph such as crossroads, corners of prominent buildings, corners of salinas (salt ponds), seaward or landward ends of jetties or piers, and ends of the airstrip, and then gone out with a Global Positioning System (GPS) to obtain the UTM coordinates of a series of ground control points (GCPs) scattered over the area covered by the aerial photograph. The location of each GCP was determined using a Differential Global Positioning System (DGPS) with a probable circle error of 2–5 m[1]. Their position was marked on a print out of the aerial and notes made of exactly where each GPS reading was taken to aid matching of column and row coordinates on the scanned image of the aerial to UTM Eastings and Northings of GCPs. We have entered most of the GCPs into a *Bilko* rectification table to save you time.

## Geometric correction

Raw remotely sensed imagery is usually distorted in some way. Geometric correction of remotely sensed imagery is carried out so that (i) it can be represented on a plane (e.g. flat sheet of paper), (ii) it can be used like a map, or (iii) it will conform to other images to which you wish to compare it. *Rectification* is the process of projecting data onto a plane and making it conform to a map projection system such as the UTM Grid System. During the process of rectification the grid of raw data (usually just column and row coordinates) must be transformed onto a new grid (usually a map coordinate system). For UTM this new grid consists of Eastings and Northings in metres from a "false" origin. *Resampling* is the process of interpolating data values for pixels on the new grid from the values of the source pixels. *Georeferencing* is the process of assigning map coordinates to image data.

Sometimes you have geometrically corrected images of the same area, which have been rectified to different grid systems (e.g. one image might have been rectified to UTM zone 30 (Northern Hemisphere) with WGS 84 spheroid/datum and another to the UK National Grid using Airy (1844) spheroid and Ordnance Survey of Great Britain 1936 datum with a Transverse Mercator projection). If you wish to compare such images, you need to rectify and resample one image to conform to the other.

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[1] With more modern equipment and removal of "selective availability" error by US Department of Defense you would expect to achieve somewhat better accuracy nowadays.

The process of making image data conform to another image is called *registration* and need not necessarily involve a map coordinate system.

To rectify an image you need to relate specific pixels in the image to known map coordinates. The map coordinates of objects, which are clearly recognisable both on the ground and on the image, may be obtained from large-scale maps, directly using a GPS or from other images that are already georeferenced. The *Bilko* rectification table allows you link raw image pixels at known column and row coordinates with known map coordinates. Each linked pixel is a GCP. When you have enough GCPs you can get the computer to calculate a transformation, which maps the raw image grid to the new grid. For a linear transform you need an <u>absolute minimum</u> of 3 GCPs, for a quadratic transform a minimum of 6 GCPs, and for a cubic transform a minimum of 10 GCPs. However, you should try to use as many as can be easily obtained (up to 20 or more for quadratic or cubic transforms) and have them as evenly distributed across the image as possible.

To assess the goodness of fit of both the overall transform and individual GCPs, the inverse of the transformation matrix is used to retransform the reference coordinates of the GCPs back to the source coordinate system. Unless there is a perfect fit of the GCPs (unlikely!) to the curve described by the linear, quadratic or cubic transformation used, then some discrepancy (error) will exist between the original source coordinates and the retransformed coordinates. The distance between the input (source) location of a GCP and the retransformed coordinates of the same GCP is called the Root Mean Square (RMS) error. This is calculated for you in the rectification table as follows:

$$\text{RMS error} = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2}$$

where $x_i$ and $y_i$ are the input (source) coordinates, and $x_r$ and $y_r$ are the retransformed coordinates (see Figure 3.1 below). You can use the overall RMS error (the square root of the sum of squares of the individual RMS errors divided by the number of GCPs used in the transformation process) to judge which transform is most appropriate and use the individual RMS errors to see if any GCPs have unacceptably high errors and should be removed from the transformation calculation to improve the fit.
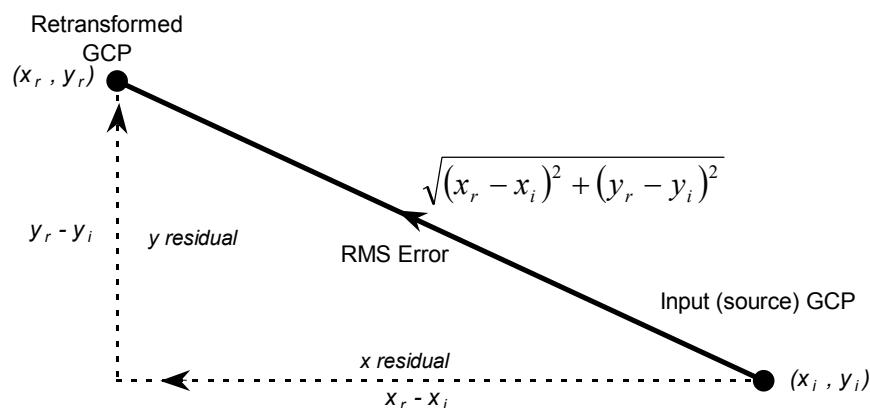


**Figure 3.1.** The calculation of the RMS error of an individual GCP.

## Lesson Outline

### Inspecting the uncorrected scanned aerial photograph

You have been presented with a scanned black-and-white (monochrome) aerial image from 1981. Before attempting to geometrically correct the image you will examine it so that you can better understand the need for geometric correction and consequences of not doing it.

*Activity:* Launch *Bilko,* select **File, Open** and make sure that **Extract** checkbox is checked and **Minimize** checkbox is unchecked. Then open the 8-bit integer image file **Aerial_subimage_raw.gif** noting the size of the image [*Hint:* remember to account for the fact that the first pixel is at coordinates (0, 0)]. Examine the image and identify the airstrip across the top of the image, the disused salinas (salt ponds) covering most of the centre of the image, the settlement in the bottom left (south-west) and the very dark strip of mangrove along the coast to the north of the settlement.

*Question:* *3.1.* How many columns and rows of pixels does the **Aerial_subimage_raw.gif** have?

*Question:* *3.2.* How many kilometres is the top of the image across if you assume that each pixel is 3.5 m wide?

To see the kind of effects that using an uncorrected image might cause, you will estimate the length of the tarmac on the runway both before geometrically correcting the image and after the image has been corrected. You have been told that the pixel size is 3.5 m x 3.5 m. Using this information and Pythagoras's theorem you can estimate the runway length. Pythagoras's theorem tells us that for right-angled triangles:

$$\text{Length of hypotenuse} = \sqrt{\left(\text{Distance in X direction}\right)^2 + \left(\text{Distance in Y direction}\right)^2}$$

This allows us to work out the diagonal distance (length of hypotenuse) between any two points on the image. Note that it is often easier to work out distances in pixels and then multiply the final result by the pixel size.

*Activity:* Click on the transect button and with the mouse lay a transect along the middle of the tarmac from the western end of the tarmac landing strip to the eastern end. Select **File, New** and then TRANSECT Document to display the transect. Make a note of the column and row coordinates at the start and end of the transect. Use this information (or **Edit, Go To**) to find the distances in the X and Y directions between the points at either end of the transect and then use Pythagoras's theorem to estimate the diagonal distance in metres along the runway tarmac.

*Question:* *3.3.* What is the estimated length in metres (to the nearest m) of the runway tarmac?

### Geometric correction of the scanned aerial photograph

The next stage is to match pixels at particular column and row coordinates to Ground Control Points (GCPs) where readings of UTM coordinates have been made. To save you time 24 GCPs have already been entered into the rectification table **South_Caicos_GCPs.tbl**.

*Activity:* Close the transect document. Select **File, Open** and set **Files of Type:** to TABLES (*.tbl), then select **South_Caicos_GCPs.tbl** as the rectification table and click on [ **Open** ] to open the table. Note that the **Master:** column is set to **Use Map (Gridded)** and contains the UTM coordinates of the GCPs, whereas the **Slave:** column

is set to the **_Aerial_subimage_raw.gif_** image and contains the row and column coordinates for the GCPs.

Initially the transform is set to Linear. The average Root Mean Square (RMS) error is shown at the head of the last column. Its units are <u>pixels</u>. Note that the GCPs are now displayed in yellow on the image. Inspect the image and note that the GCPs are reasonably evenly distributed over the image. When you have satisfied yourself of this, make the rectification table the active window and answer the following questions.

*Question:*     *3.4.* (a). What is the average RMS error for a linear transform? (b). What is this expressed in metres (assuming a pixel size of 3.5 m)? [Express answer to nearest 0.1 m.]

*Activity:*     Right-click on the rectification table and change the Transform to quadratic. Note the dramatic improvement in the average RMS error.

*Question:*     *3.5.* (a). What is the average RMS error for a quadratic transform? (b). What is this expressed in metres (assuming a pixel size of 3.5 m)? [Express answer to nearest 0.1 m.]

*Activity:*     Right-click on the rectification table and change the Transform to cubic. Note the slight improvement in the average RMS error.

*Question:*     *3.6.* (a). What is the average RMS error for a cubic transform? (b). What is this expressed in metres (assuming a pixel size of 3.5 m)? [Express answer to nearest 0.1 m.]

The huge improvement in the RMS error when the transform is changed from linear to quadratic suggests that a linear transform is totally inadequate to correct the distortions of this image. By contrast, the relatively minor improvement in the RMS error when the transform is changed from quadratic to cubic suggests that a quadratic transform is probably sufficient. Using a higher power transform will always improve the fit (reduce the overall RMS error) but cubic transformations are seldom necessary.

Given a 2–5 m probably circle error for the DGPS fixes as well as the likelihood of at least a one pixel (3.5 m) error in the X and/or Y direction in identifying the correct column and row coordinate on the image, an overall RMS error of around 5 m seems about as good as one is likely to get with the DGPS and image being used.



**Figure 3.2**. Locations of GCPs #24 to #26 on the scanned aerial photograph.

The next stage is to enter the three remaining GCPs into the rectification table. The differential GPS readings for these three GCPs are listed in Table 3.1 below and their locations on the image shown in Figure 3.2 above.

**Table 3.1.** Global Positioning System UTM coordinates for GCPs#24 to #26.

|  | Description | Easting | Northing |
|---|---|---|---|
| GCP#24 | Centre of crossroads in town (north) | 237437.5 | 2379087.5 |
| GCP#25 | Centre of crossroads in town (south) | 237850.0 | 2378512.5 |
| GCP#26 | Salt pond boundary wall corner | 238431.3 | 2378793.8 |

*Activity:*    In the rectification table click on the Description for GCP#024 and type in the description for this GCP, then press the *<Tab>* key and enter the Easting and Northing separated by a space or a comma. At this point switch to the ***Aerial_subimage_raw.gif*** image and position the cursor as close as possible to the exact centre of the crossroads indicated in Figure 3.1 using the mouse. Then use the arrow keys with *<Ctrl>* depressed for final positioning. [*Hint:* It is easier if you zoom in to 200% to 400% to do this]. When you are satisfied that the cursor crosshair is right in the middle of the crossroads, press the *<Insert>* key to insert the column and row coordinates into the rectification table. [The correct column and row coordinates are (214, 685) and you should be within 1 pixel of these coordinates].

Repeat the process for GCPs #25 and #26. When all GCPs have been entered, right-click on the rectification table and <u>make sure</u> that the **Transform** is set to Quadratic. Check the average RMS for all 27 GCPs [*remember:* first GCP is #000]. This should be approximately 1.5. If not, then check that your new GCPs are correctly located!

*Question:*    *3.7.* (a). What column and row coordinates do you have for GCP#25? (b). What column and row coordinates do you have for GCP#26? (c). What is the average RMS error for all 27 GCPs?

You now have a good series of fairly evenly spaced GCPs scattered across the most of the image. This should allow good rectification of the scanned aerial photograph with good confidence in the results. Before doing this you should note two further points about the raw image.

*Activity:*    Firstly, although you have established details of the UTM Eastings and Northings and corresponding column and row coordinates for 27 GCPs in the image in the rectification table, if you click on the image you still only see column and row coordinates returned on the Status bar. Check this out. Note also that in the **View** menu, you do not have the option to view **Coords**.

Secondly, note if you hover the mouse pointer over the cross marking the position of each GCP you will see a pop-up that shows the GCP number and its description. If GCPs are very close to the image edge so that the yellow numbers are not fully visible, this is useful.

Finally, you need to check whether any individual GCPs are likely to spoil the fit of the image, that is, have anomalously large RMS errors associated with them. For the purposes of this exercise it has been decided that GCPs with RMS errors greater than 10 m should be rejected.

*Activity:*    Work out how many pixels (to 2 decimal places) 10 m is equivalent to. Then check the rectification table to find out if there are any potentially problematic pixels that should be rejected.

*Question:*    *3.8.* (a). Which GCP has the greatest (worst) RMS error? (b). What is this error in pixels? (c). Should this GCP be rejected on the basis of the criterion stated above?

*Activity:*     You should have found a single GCP that needs to be rejected. Uncheck the checkbox for this GCP in the rectification table so that it is displayed in cyan on the image. The average RMS error should reduce to approximately 1.368 pixels (about 4.8 m).

At this point you need to link the UTM coordinates to the image and fix the transform prior to resampling. This is done by copying the rectification table to the clipboard and then pasting it to the image.

*Activity:*     Click on the rectification table so that it is the active document and select the Copy button to copy the table. Now click on the ***Aerial_subimage_raw.gif*** image and click on the Paste button. Note that **View, Coords** can now be activated and that UTM coordinates now appear on the Status bar. If you position the cursor on the centre of the cross for any GCP, the Status bar will now show the coordinates of the centre of the pixel in which the GCP occurs. Compare the Status bar positions (pixel centres) for one or two GCPs with the UTM coordinates (read off the GPS) that are listed for the GCPs in the rectification table. Values should usually be within a few metres for both Eastings and Northings.

Although the computer can now calculate the UTM coordinates of each pixel, the image geometry has not yet been warped to display the image correctly in the new coordinate system. For this to occur the image must be resampled and redisplayed on a UTM grid.

*Activity:*     With the image as the active document, select **Image, Resample**. This brings up the **Resample** dialog box with four tabs: **Window, Pixel, Image** and **Interpolation**. For the interpolation method, select Cubic convolution[2] and click the Apply button. Then click on the **Window** tab and set the **Easting (X):** to 236670 **to:** 240290 and **Northing (Y):** to 2381490 **to:** 2378110 and click the Apply button. This provides a window sufficiently large to accommodate a bit of warping of the original image (slightly larger than the original image in each dimension). Next click on the **Pixel** tab and set both pixel **Width:** and **Height:** to 3.5 (i.e. 3.5 m) and click Apply. [The default settings of 3.6 and 3.4 suggest that some warping is needed.] The original image was 990 columns by 980 rows. Click on the **Image** tab to find out the size of the new image in rows and columns.

*Question:*     *3.9.* What size is the resampled image going to be in columns and rows?

The original image was the same width at top and bottom. You will now check to see whether geometric correction has changed this, by comparing the length of two transects, one at the top of the image and one at the bottom.

*Activity:*     When you have applied the correct settings for interpolation, window and pixel size, click on OK to carry out the resampling. Select the resampled image and lay a horizontal transect from west to east from the top left hand corner of the image at column and row coordinates (1, 10) to the last non-zero pixel in that row at coordinates (1033, 10). Find out the east-west distance across top of the image [*Hint:* switch to viewing UTM coordinates once the transect is in place]. Starting at the bottom right of the image – column and row coordinates (983, 951) – draw a horizontal transect to the first non-zero pixel in the same row and measure the east-west distance across the bottom of the image.

*Question:*     *3.10.* (a). What is the distance in metres across the top of the resampled image (to pixel edges) – from column and row coordinates (1, 10) to (1033, 10)? (b). What is the

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[2] In this instance we are looking to achieve a reasonably smooth resampled image and are not interested in preserving spectral values; thus Cubic convolution is perhaps the best method and Bilinear interpretation which involves some averaging of pixel values would also be appropriate.

distance in metres across the bottom of the resampled image (to pixel edges) – from column and row coordinates (983, 951) to (5, 951)? (c). What is the difference in distance across the image between rows 10 and 951 (<u>not</u> counting zero value pixels!)?

*Question:*     *3.11.* What do you estimate the length in metres (to the nearest m) of the runway tarmac to be now, using the geometrically corrected resampled image?

*Question:*     *3.12.* How wrong was your estimate of the runway length using the raw (uncorrected) image?

The answers to questions 3.10 to 3.12 show you how important geometric correction is. If you had just assumed the aerial photograph was a true (undistorted, map-like) representation of the area, you would have made considerable errors, underestimating distances in the north of the image and overestimating distances in the south of the image due to the slightly oblique angle at which the image was taken.

To see more clearly how the aerial photograph was distorted, you will now stack the raw and geometrically corrected images in same sized windows with their top left corners mapped to the same point. From your earlier study of the resampled image you know that its top left hand corner is at column and row coordinates (1, 10) in the resampled image window. You thus need to (i) copy the raw image, (ii) make sure the image cursor is on column and row coordinate (1, 10) in a blank image the same size as the resampled image, and (iii) paste the raw image into the window.

*Activity:*     Firstly, you need to retrieve a version of the raw image <u>without</u> the UTM coordinates applied. To do this, close the rectification table and the ***Aerial_subimage_raw.gif*** image. Then reopen the ***Aerial_subimage_raw.gif*** image, which will now be as it was before you started rectifying it. Select all of the image and Copy it.

    With the geometrically corrected image as the active image select **Image, Connect** and connect the image to one blank in a stack. Select the blank image using the **Selector** drop-down list. Using either **Edit, Go To** or the mouse and arrow keys, place the image cursor on coordinates (1, 10). Paste the raw image into the blank window. Zoom out so that you can see the whole image and click on the Loop button ▮▮ (or select **Image, Animate** and click on OK). You will see clearly that the original aerial photograph was considerably distorted. When you have finished close all images.

The amount of distortion suggests that the original aerial photograph, of which the image was a part, was perhaps not flown as part of a vertical aerial survey or has become distorted with time. A normal aerial survey photograph would be expected to require much less geometric correction whilst near-vertical photographs taken from hand-held cameras (and thus likely to be somewhat oblique) would be expected to require considerable correction.

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