APPLICATION 27

Creating a mosaic using a DTM and small format aerial photographs

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Summary

One of the first steps in any settlement improvement project is the preparation of a base map. Whenever there are no recent maps of the project area, the available (old) maps need to be updated. This can be done by field survey, but this tends to be rather time consuming and expensive.

An alternative is the use of small format aerial photography (SFAP), which provides an efficient means for producing an updated map of the project area. Moreover, the aerial images are also a useful communication tool in discussions between planning professionals and local residents, concerning development related problems and possible improvements.

This exercise focuses on creating a photo mosaic of an urban area in Dar-Es-Salaam, Tanzania. In the area covered by the mosaic height differences do exist. The direct linear transformation is used to correct the aerial photographs geometrically for relief displacement. This can only be done when a Digital Terrain Model (DTM) is available. In this exercise the DTM is derived from a contour map. Local field tiepoint data are used for georeferencing the photographs.

Getting started

This application is written for use with the ILWIS 3.0 software.

The data for this case study can be downloaded from the ILWIS Internet site at http://www.itc.nl/ilwis/. If you have already installed the data on your hard disk, you should start up ILWIS and change to the subdirectory where the data files for this chapter are stored. If you did not install the data for this case study yet, please download the data first.

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- Double-click the ILWIS icon on the desktop.

  Use the Navigator to go to the directory where the data files for this chapter are stored.

Now you are ready to start the exercises of this case study.

27.1 Introduction

Small format aerial photography (SFAP) offers a relatively low cost and simple do-it-yourself alternative to obtain up-to-date aerial photo coverage. The advantages make it very attractive to apply. However, every advantage has its disadvantage. One disadvantage should be acknowledged: the small format means that a relative small area is covered by a single photograph (as compared to the regular 23 cm aerial survey photography of the same scale). The need to create mosaics to cover larger areas is therefore likely to arise.

SFAP is basically a technique best suited to relatively small areas, where no precision mapping is required, but where the photo is used as a source of thematic information. It can be particularly useful when no sufficiently recent large format photos of the appropriate scale and coverage can be procured, and when no time or money is available for ordering new large format aerial photography *(Hofstee, 1984)*.

The cameras used are common off-the-shelf professional and good-quality amateur cameras, usually the 35 mm camera (image size 24 x 36 mm), or when available the 6 x 6 cm or 70 mm camera (image size 56 x 56 mm). The cameras have not been designed for metric qualities, therefore one cannot expect lens calibration, film flattening devices, or forward motion compensation. Nevertheless, e.g. for cases like mapping soil and vegetation patterns or urban changes the accuracy is acceptable *(Warner et al 1996)*.

The photos can be georeferenced (and rectified) when the coordinates of a number of tiepoints are known. The simplest transformation is the projective transformation, which requires a minimum of 4 tiepoints and a flat terrain. In this case the study area has some height differences and therefore the direct linear transformation is used to correct for relief displacement. However, to execute this direct linear transformation a Digital Terrain Model (DTM) must be available. In this application the DTM is derived from a contour map (in digital format).

A group of georeferenced photos can be assembled into a mosaic to cover a larger area. In this exercise eight small format aerial photographs will be glued into a single mosaic.

27.2 Obtaining small format aerial photographs

The planning of a flight to obtain SFAP is in principle the same as for a normal large format survey flight for vertical photography with stereoscopic coverage.

The prime factor to consider is the scale of the negatives of the photographs. The scale should be large enough to clearly see the details, which are needed in the interpretation of features, on a standard enlargement (e.g. size 10 x 15 cm, which means a factor 4.5 enlargement of the negative). A larger scale may be convenient to detect the features easily, but the cost is an increased number of photographs to cover the area and to interpret.

See Figure 1 for other factors to consider in the survey flight planning.

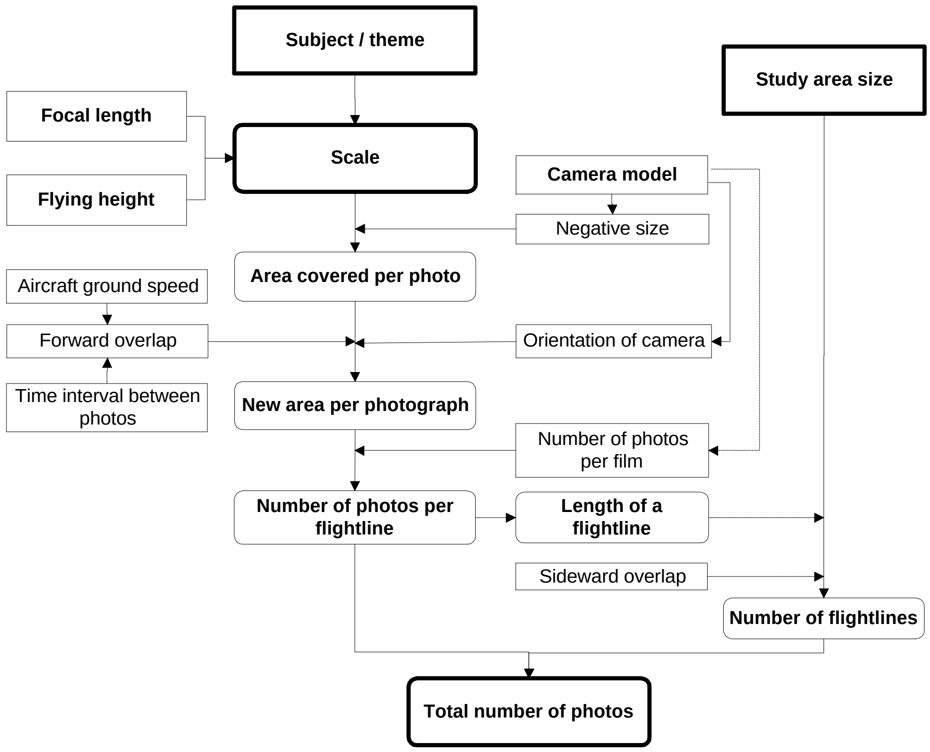

Figure 1: Small format vertical aerial photography flight planning. Please note that the orientation of the camera (parallel or perpendicular to the flight line) only applies to non-square formats, e.g. 24 x 36 mm.

27.3 Available data

In this exercise 8 small format aerial photographs will be georeferenced to obtain a base map for the preparation of a map with the current buildings and land uses.

`Image07.tif`,	Near vertical aerial photographs of Dar-Es-Salaam,
`Image09.tif`,	Tanzania made on 3 December 1999.
`Image18.tif`,	Flying height around 500 m above terrain.
`Image19.tif`,	Camera Nikon with 50 mm lens, image size 36x24 mm.
`Image22.tif`,	Negatives enlarged to A4 size, scanned at 150 dpi and
`Image25.tif`,	stored in TIF format.
`Image29.tif`,	
`Image34.tif`	
`Sfap07`, `Sfap09`	ILWIS map views of two photos showing the locations of GPS observations in `Image07` and `Image09`.
`Building1992`	Polygon map of existing buildings in 1992.
`Contour`	Segment map with contour lines of the study area.

27.4 Direct linear transformation

It is recommended to create a georeference direct linear and execute a direct linear transformation when:

- you have small format photographs, i.e. photographs taken with a normal camera, or in general *photographs without fiducial marks*, and
- the terrain covered by the photograph has clear *height differences*, i.e. you need to correct for tilt and relief displacement, and
- a *Digital Terrain Model* (DTM) of the area is available.

A georeference direct linear requires at least 6 tiepoints (also called ground control points). For each tiepoint, RowCol numbers from the photograph and real world XY-coordinates are stored. Height (Z) values can be supplied by the user, or are obtained through the XY-coordinates from the DTM.

The flying height, the camera projection center (X_0, Y_0, Z_0), the camera axis angles (a, ß, ?) with the X, Y, Z axes are calculated from the tiepoints.

When all tiepoints in the georeference direct linear fit in one (horizontal or tilted) plane in XYZ-direction, a projection center cannot be calculated. This will be indicated with an error message: singular matrix, i.e. the tiepoints are coplanar. The matrix will remain singular when only one tiepoint is outside the common plane. When the tiepoints almost fit in one plane, i.e. when tiepoints are near to coplanar, then the direct linear transformation *seems* to work, but it is not reliable.

A georeference direct linear has the highest accuracy within the 3D envelope bounded by the tiepoints; thus the better the XYZ spread of tiepoints, the better the transformation will work. To obtain a reliable georeference direct linear, it is necessary that *at least* 2 tiepoints clearly deviate in Z-direction from a (horizontal or tilted) plane. Therefore the tiepoints should be well spread over the photograph (*XY-direction*), and the tiepoints must have different height values in the DTM (*Z-direction*).

The Additional Info tab of the Properties sheet shows more information about the direct linear transformation equations, the estimated camera projection center, the camera axis angle with respect to the XYZ-axes, and the calculated approximate pixel size in the photograph.

27.5 Creating a DTM

Before georeferencing the photos a Digital Terrain Model (DTM), i.e. a digital representation of terrain relief, has to be created. A DTM can be stored in different manners (contour lines, TIN, raster) and may also contain semantic, relief-related information (breaklines, saddlepoints).

A Digital Elevation Model (DEM) is a special case of a DTM. A DEM stores terrain elevation (surface height by means of a raster). Elevation refers to a height expressed with respect to a specific reference. (*Janssen et al, 2000*).

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- Create a DTM from segment map `Contour`. Use `Keko` as GeoReference and the system Domain `Value` with a Value Range from `0` till `30` and a Precision of `0.1`. Call the Output Raster Map `DTM`.

27.6 Georeferencing images and applying a transformation

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- Import the 8 aerial photographs `Image07.tif`, `Image09.tif`, `Image18.tif`, `Image19.tif`, `Image22.tif`, `Image25.tif`, `Image29.tif` and `Image34.tif`.
- Display the raster maps and zoom in to see more details. Observe that the maps have no coordinates.
- Open the File menu in the map window of raster map `Image07` and select Create, GeoReference. The Create Georeference dialog box is opened.
- Enter `Image07` for the GeoReference Name and select the option GeoRef Direct Linear.
- Select raster map `DTM` as DTM and click OK. The GeoReference Editor appears.

Two different methods are applied to obtain tiepoint (or reference point) coordinates: *GPS observations* and *image-to-image registration.*

27.6.1 Georeferencing the photos with GPS field observations

Two map views, `Sfap07` and `Sfap09` are available which replace the hard copy photographs. These photographs are used in the field to identify and annotate places where GPS observations have been made. Such places can for example be house corners, wall, fence or pavement corners, manhole covers or electricity poles. The GPS observations made for `Image07` and `Image09` are respectively listed in the Tables 1 and 2.

Table 1: GPS observation points and coordinates for `Image07`.

Name	Coordinates (X, Y)
pnt 1	530559, 9245085
pnt 2	530596, 9244983
pnt 3	530672, 9245036
pnt 4	530692, 9244892
pnt 5	530558, 9244878
pnt 6	530538, 9244798
pnt 7	530723, 9244801
pnt 8	530802, 9244785
pnt 9	530826, 9244867
pnt 10	530758, 9244939
pnt 11	530767, 9245020
pnt 12	530881, 9245048
pnt 13	530860, 9244976
pnt 14	530871, 9244796

Table 2: GPS observation points and coordinates for `Image09`.

Name	Coordinates (X, Y)
pnt 1	530693, 9244890
pnt 2	530612, 9244904
pnt 3	530577, 9244797
pnt 4	530550, 9244713
pnt 5	530519, 9244637
pnt 6	530637, 9244607
pnt 7	530658, 9244682
pnt 8	530721, 9244688
pnt 9	530673, 9244767
pnt 10	530751, 9244776
pnt 11	530785, 9244836
pnt 12	530855, 9244781
pnt 13	530803, 9244673
pnt 14	530739, 9244558

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- Open map view `Sfap07` (an image without coordinates, just like a hardcopy photo in the field) and zoom in on `pnt1`.
- Find the same place on `Image07`, locate the mouse pointer on it and click. The Add Tie Point dialog box appears. The row and column number of the selected pixel are already filled out.
- Enter the correct X, Y coordinates according to Table 1 and click OK. The first reference point will appear in the tiepoints table.
- Repeat this procedure for `pnt2`-`pnt14` (in this order) and observe the Sigma value and Flying Height in the GeoReference Editor. If the Sigma value is too high (i.e. > `3.000`), some tiepoints have to be deselected (by putting `False` in the column `Active`) as they are not defined accurately enough. Tiepoints that are not accurate enough will have very high values in the `DRow` and/or `DCol` columns.

- Find points with very high residuals in the DRow and/or DCol columns. These residuals are the deviations (measured in image pixels) from the ideal. Have a closer look at these points on the photo to see what could be the cause of the high values.
- Close the GeoReference Editor when you are finished. Image07 is now geo-referenced.
- Repeat the procedure to georeference Image09.

When georeferencing Image09, at a certain point the matrix becomes singular, meaning that all points are coplanar. Observe the Z-values for these points. Adding some more points and the Sigma value can be calculated again. Observe again the Z-values of these points.

! The Sigma value indicates the accuracy of the transformation. The Sigma value should be multiplied by the pixel size to obtain the accuracy in meters.

For realistic results a minimum of 10 points should be active. The best way to reach the compromise between the most active points and the lowest sigma is to deactivate the first point that reduces the sigma significantly (red color). Then repeat this procedure until the sigma does not change significantly. Be sure that the active points are still well distributed over the image.

27.6.2 Georeferencing the photos with image-to-image registration

For the study area an outdated topographic map exists, which can be used as a reference map to find tiepoints for the images. The polygon map Building1992 is a map showing the outlines of buildings as interpreted by the mapmaker from aerial photographs that were made in 1992. One can expect quite a few additional buildings on the recent photos. Also some buildings may have been removed.

The map is not a photographic image with a georeference, comparable in contents with the photo that should receive a georeference. It shows the (orthogonal) projection on the ground of the boundaries of the roofs of existing buildings, whereas the aerial photo shows the roof and sometimes parts of the walls, but not projected orthogonally on the ground. The tiepoint, therefore, should in principle be a point that is at a height defined in the DTM (that is normally a point *on the ground*). The orientation of the polygon map is North. The orientation of the non-resampled photos can deviate considerably from a North orientation, up to 180°.

The first step in the image-to-image registration is a comparison of the map and the photo: look for long streets and large buildings. If you find a corresponding point, zoom in on the details (street crossings, groups of small buildings) to get a confirmation. Pay attention to deviating building shapes, e.g. non-rectangular or L-shaped buildings. Be aware of errors in the map! Some buildings may be misrepresented, or have changed their shape after reconstruction. Before establishing a tiepoint, confirmation is important: do not jump to conclusions.

On vertical aerial photographs relief displacement (related to terrain relief and building heights) plays a role. The higher the object and the further away from the nadir point, the more the object is displaced from its position in an orthogonal projection (which is the normal map model). On oblique aerial photographs there is the additional influence of the deviation from the vertical of the lens axis.

The angle of obliquity and the building roof height relief displacement will influence whether it is advisable to use a roof corner or use an approximate ground point (e.g. between two closely spaced buildings).

After a tiepoint has been defined, follow a step-by-step route to the next tiepoint. Use reference buildings that you recognize as identical on the map and the photo. Follow the mouse pointer (on the polygon map) with your finger on the photo on the screen.

When 6 tiepoints have been defined, the X- and Y-coordinates of the photo are calculated and appear in the lower right hand of the map window. From that moment on it is possible to add polygon map `Building1992` as a layer to the map window showing the photo image (Tip: use Boundaries Only and Boundary Color `White`).

The pattern of building outlines on top of the photo image may be helpful to locate a building to be used for a next tiepoint on the photo as well as on the polygon map `Building1992`. However, be careful, the overlay will not fit perfectly as long as the photo georeference is not perfectly fitting the polygon map georeference.

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- Display `Image19` on the left side of your monitor screen and create a GeoRef Direct Linear. Type `Image19` for the GeoReference Name and use `DTM` as the Digital Terrain Model.
- Display polygon map `Building1992` on the right side of your screen.
- Choose a tiepoint on `Image19` for which you can find the coordinate pair in the polygon map `Building1992`.
- Zoom in on the chosen location, and click the point in `Image19`. The Add Tie Point dialog box appears.
- Go to the map window with polygon map `Building1992` and click the point, which corresponds to that position. The coordinates of this point (X and Y from the polygon map, and Z from the DTM) will be entered automatically in the Add Tie Point dialog box.
- Click OK to close the Add Tie Point dialog box.
- Identify around 15 tiepoints, well distributed over the image and with a sigma value less then 2.

- Repeat this procedure for `Image22`.
- The tiepoints of the other 4 images have already been added. The resulting `*.grf` and `*.gr#` files are stored in a zip file called `Georeference27.zip`. Unzip this file into your ILWIS working directory to use them.
- Change the Properties of image `Image18`, `Image25`, `Image29` and `Image34` to their corresponding georeference.

In some cases (for example for benchmarks) the real height of the tiepoints is known, and the Z-value of the DTM can be corrected. In the GeoReference Editor, a column Z is available to introduce the real height.

27.7 Resampling the photos and creating a mosaic

The georeferenced photo images might be resampled and displayed to apply the now defined transformation. It can be done individually to obtain a resampled map for every image or the maps can be glued together to create a mosaic of all the photographs (Figure 2).

This resampling and gluing can be a lengthy process, but when done in a correct way, time can be saved.

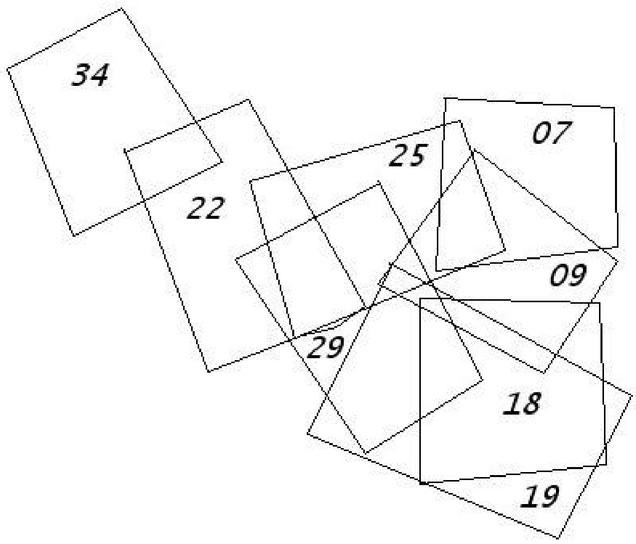

Figure 2: Location map of the georeferenced and resampled photos.

Before the process can start the domain of the images has to been changed from picture to color. Picture domains can only contain 256 different colors, whereas color domains can store the information in 24-bit mode (or 16 million colors).

Gluing maps with a picture domain will result in a final map with more than 256 colors, which cannot be represented in a useful way.

The following MapCalc statement can be applied on the Command line of the Main window to change from a picture domain to a color domain:

```
Mapcolor1:=Color(Map1.red,Map1.green,Map1.blue)
```

However, it is much more convenient to use a script to handle all 8 images.

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- Select Create, Script from the File menu of the Main window. The Script editor is opened.
- Create a script that changes the domain of each of the 8 images from the picture to the color domain. Call the output raster maps `Imcol07`, `Imcol09`, `Imcol18`, etc.
- Save the script so that you can edit it when there are errors in it and run the script to convert the domains. Make sure that none of the images is open. After domain conversion the resampling and gluing process can start.

First a georeference corners for image `Imcol07` will be defined. In the Create GeoReference dialog box the pixel size has to be selected. It does not make sense to select a pixel size that is smaller than the pixel size (ground dimensions) of the original image. Original image here means: the image that was the output of the scanning process. In this exercise 0.5 m will be used to reduce the processing time (e.g. 0.25 m means 4 times as many pixels to process).

By default the boundary values (X_{min}, Y_{min}, X_{max}, Y_{max}) of the input map are already filled out in the new georeference corners. These boundary values define the area to be resampled. When other maps are added in the gluing process, their coordinates will automatically expand the resampling area. This is a much more efficient resampling procedure than first defining the total mosaic area as the resampling area. However, the coordinate system definition should already cover the full mosaic area.

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- In the Catalog click with the right mouse button on `Imcol07` and select Image Processing, Resample from the context-sensitive menu. The Resample Map dialog box is opened.
- In the Resample Map dialog box accept `Imcol07` as input Raster Map and `Nearest Neighbour` as Resampling Method.
- Type `Imcol07rs` for the Output Raster Map and create a GeoReference `Keko1` with a Pixel size of `0.5` meter and Coordinate System `Keko`.
- Accept the X_{min}, Y_{min}, X_{max}, Y_{max} as already filled out by the system,

click OK in the Create GeoReference dialog box and click Define in the Resample Map dialog box.

- Create a script Mosaic, enter the following command:
```
Mosaic:=MapGlue(Imcol07rs,Imcol09,Imcol18,Imcol19,Imcol22,Imcol25,Imcol29,Imcol34,Replace)
```
- Execute the script and show the final result. The orientation of the photographs should be similar to Figure 2.

! This process may take quite some time, depending on the specifications of the computer.

When observing the final result some irregularities are visible, e.g. a tire of the airplane. To avoid these irregularities two methods can be applied. One is by changing the order in the gluing process in such a way that an image with such an irregularity will be overlayed with another image. The other method is creating sub maps with the SubMap of Raster Map operation, cutting off the undesired parts.

27.8 Applications

Among the main applications of SFAP, updating plays an important role, particularly providing a record of the actual situation in areas that are changing continuously and fast, e.g. unplanned residential areas in cities in developing countries.

A mosaic made from a series of small format aerial photos can provide a means for the production of an updated map of such an area, but also of (for instance) a disaster area (flooding, earthquake, etc.).

A number of other potential applications are evident and regularly practiced.

To illustrate the point, the exercise SFAP mosaic of the Keko Mwanga area in Dar-Es-Salaam, Tanzania, actually has been used for the following activities:

- to update the 1992 topographic base map of the settlement, primarily for delineating new and modified buildings;
- to identify and prioritize the problems that local residents are faced with in this area. The mosaic has proved to be very useful in group sessions, as persons easily understand it with little or no previous exposure to maps or aerial photographs;
- in discussions by the community on the location of an extension to the primary school;
- to locate solid waste collection points by an NGO working in the area;
- improvement of the building registration system, which is the basis for local revenue collection, by the local government.

References

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