OPEN SOURCE GIS: A GRASS GIS Approach

Second Edition

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Chapter 10

PROCESSING OF AERIAL PHOTOS

Aerial photography provides a common base for large scale mapping. It has been widely used for creating and updating maps as well as for maintaining up to date GIS databases. Aerial photos can be used to extract georeferenced data representing topography, landforms, vegetation cover as well as man-made features. Besides creation of thematic maps, area and distance measurements at a large scale (in comparison to satellite-based methods) are often performed. Digital processing of aerial photos in GRASS allows the user to incorporate them into a GIS database. To minimize distortions, mainly displacement due to relief and airplane attitude, orthophotos are generated from (scanned) aerial photographs using a digital elevation model and a referenced map. They combine the characteristics of an aerial photo with the geometric qualities of a map, showing all objects in their precise geographic position.

In the first part of this chapter we introduce generation of orthophotos, in the second part we explain image segmentation of aerial photos for land use classification and edge detection.

10.1. BRIEF INTRODUCTION TO AERIAL PHOTOGRAMMETRY

Before going into details of generating a digital orthophoto, we describe the basic terminology used in aerial photogrammetry. Aerial photos are usually taken with overlap of around 60% for stereoscopic analysis; however, this method is not covered here.

This chapter focus is on vertical aerial photos; however, a brief description of oblique aerial photos processing is included in Section 10.3.3. The aerial photo geometry is shown in Figure 10.1. Assuming that the aircraft which takes

the photos moves (in the ideal case) over the target area without any deviation, the plumb line from the camera will be perpendicular to the horizontal ground plane. This case is called a true vertical image. The plumb line is also called the *optical axis*. Up to deviation of $3°$ in each direction, the image is called a tilted vertical image. If the inclination exceeds $3°$, it is referred to as an oblique image. The nadir (also called plumb point) is the point on the earth's surface (datum plane) which lies exactly below the recording camera. If a photo is taken without deviations from the plumb line, then the nadir will be in the image center (principal point).

If the aircraft was tilted (oblique photo) then the principal point is not identical with the nadir. The principal point is found by connecting opposite fiducial
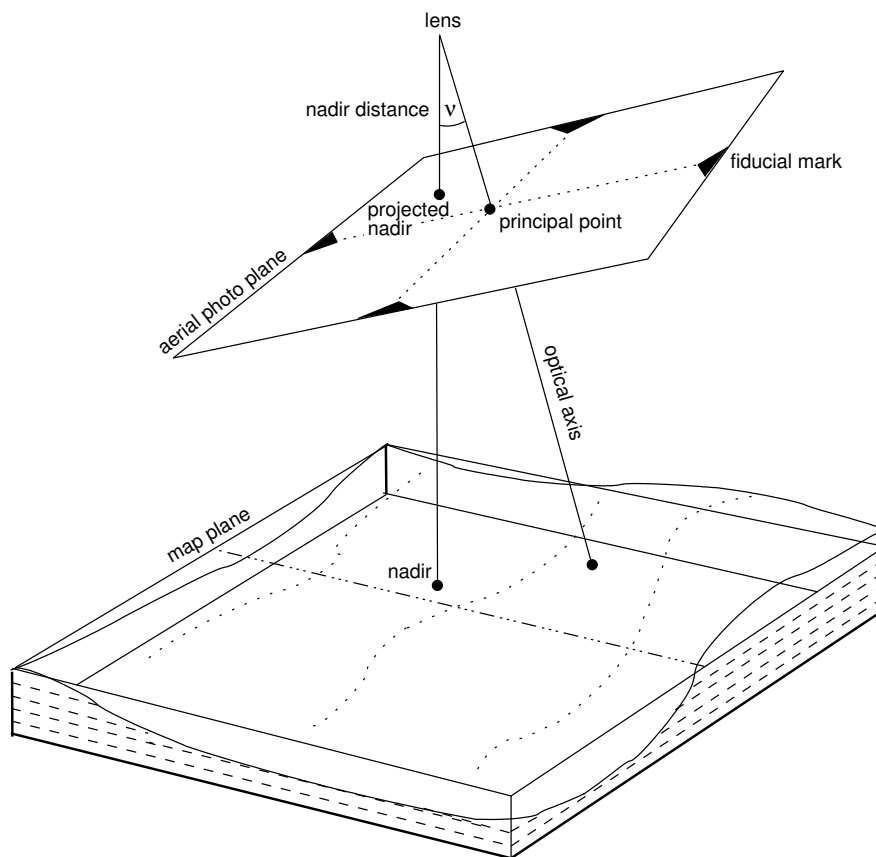

Figure 10.1.   Aerial photo terminology (adapted from Neteler, 2000:178)

marks through lines, it is the point where these lines intersect. For oblique photos the nadir is offset from the principal point, the angle between the two being called the nadir-distance (see Figure 10.1). In such case the nadir can be derived by connecting the alignments of vertical objects such as trees or buildings.

A vertical aerial photo is in central projection. This projection can also be assumed for the above mentioned slightly tilted vertical photos. There are significant differences between an aerial photo and a map (which is in orthogonal projection). Because of central projection aerial photos are free from displacements only in the nadir. Displacements increase from the nadir towards the image edges (Hildebrandt, 1996:151), which requires ortho-rectification. These displacements are intensified by uneven topography (see Figure 10.2) or increased aircraft tilt.

Elements of an aerial photo. In an analogous aerial photo metadata are displayed in the annotation bar (instrument strip). It is usually a side bar that includes information about the altimeter, aircraft attitude, watch, approximate focal length and photo counter of the camera. The camera calibration certificate describes the calibrated focal length of the camera that was used to take the photos. It also describes measured distortions within the camera, and the center of symmetry, the principal point (PP). The provider of the photo should be able to make this report available to the user. Ideally, the principal point should fall directly on the intersection of the radii at the center of the picture, which is usually not the case. The small deviation on the order of a few micrometers is relevant for a precise orthophoto. Additionally, the fiducial marks numbering scheme should be given in a diagram (Fig. 10.4 shows examples).
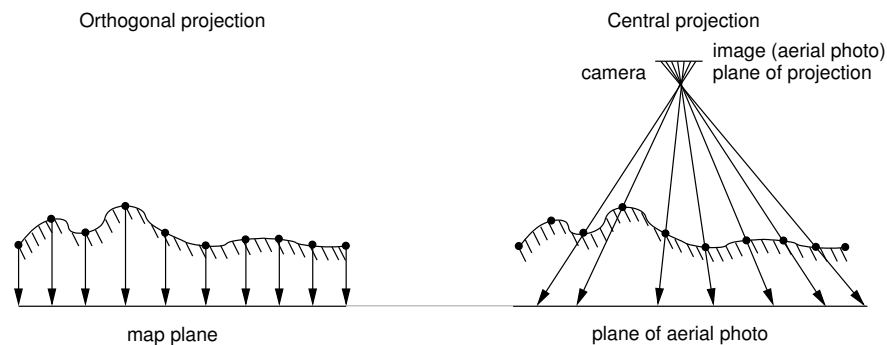

Figure 10.2. Terrain mapping to map plane (orthogonal projection) and aerial photo plane (central projection) (adapted from Albertz, 1991). Objects are displaced in the aerial photo (right) due to relief impact

Only if the report is unavailable, standard camera parameters may be taken from literature, if focal length or camera type are known (e.g. Hildebrandt, 1996:80).

Aerial photos and map scale.   The averaged image scale m_b (or the image scale number M) is elevation-dependent and can be calculated as follows:

$$M = \frac{h_g}{f} \tag{10.1}$$

$$m_b = \frac{1}{M} \tag{10.2}$$

The height above ground h_g [in meters] is a function of the topography, the terrain elevation above sea level has to be subtracted from the aircraft's recorded altitude above sea level. The focal length f of the camera is printed approximated (in millimeters) on the aerial photo, or, preferred, given correctly in the calibration certificate. The value must be changed to meters for the formula above. M is the image scale number. The image scale m_b which we are interested in can be derived from Equation 10.2. In general, higher terrain elevations within the aerial photo are recorded in larger scale than lower terrain elevations (Hildebrandt, 1996:152). Furthermore, the horizontal displacement depends on the elevation according to the central projection. Therefore, Equation 10.2 can be used to obtain only an averaged scale for the aerial photo. During ortho-rectification, the displacements are eliminated as the terrain undulation is taken into account.

The image scale is usually not constant over the covered area: If the aircraft was horizontally tilted, then the image scale of the down-side (whose distance to ground is decreased) will be larger than the scale of the up-side. Undulated terrain adds further bias on the overall scale. If the terrain undulation covered by the aerial photo is relatively small it is possible to use an unrectified aerial photo for area or distance measurements. In such a case, minor distortions are ignored (Bierhals, 1988:91). The unrectified photo can be used, if the elevation range in this photo is less than 1/500 of the image scale number. For example, if an aerial photo was taken at a average scale of 1:10,000, the photo may be used unrectified if the elevation range does not exceed 20 m (10000/500=20). Otherwise, an orthophoto should be generated as described below.

The earth's curvature is another factor that affects aerial photos. It becomes a relevant factor only for high altitude or orbit-based images (such as for images from the Russian KVR1000 or similar systems). Note that also shrinking and stretching of film material may cause displacements as well as the usage of a non-photogrammetric scanner.

10.2. FROM AERIAL PHOTO TO ORTHOPHOTO

To generate an orthophoto we need a digital elevation model (DEM) and a topographic reference map. The elevation model is required to normalize the terrain undulation. The raster resolution of the DEM should be similar to the resolution of the aerial photo. Usually such high-resolution DEMs (raster cell length below 1 m) are not available. Therefore, interpolation of a given DEM to a higher resolution, as shown in Section 5.3.4 and Section 7.3.1, is recommended to minimize displacement effects. The topographic reference map is needed to find corresponding ground control points (GCPs) between aerial photo and this map for geocoding. The map scale of the reference map should at least match the average scale of the aerial photo (for example 1:5000), but should be probably larger to provide more details for improved geocoding accuracy. The ground control points are required to register the image xy coordinate system to a georeferenced coordinate system (like UTM or Gauss-Krüger).

Metadata like time stamp, flight altitude above the sea level, tilt, and focal length will be taken from the calibration certificate and the annotation bar. An important requirement are the camera parameters.

In general "true" orthophotos and "pseudo" orthophotos are distinguished. In true orthophotos all elevated objects such as building roofs are corrected for their displacement due to the central perspective. This means that displacement-corrected buildings are seen from above which leads to no-data areas where the displaced roofs have been hiding the ground (on the buildings' back sides as seen from the nadir of the aerial photo). To create true orthophotos, you need an elevation model containing all individual building heights. High resolution DEMs can be produced from stereo measurements of the original aerial photo stereo pairs or from LIDAR flights which are done to create surface elevation models (compare Section 7.3.4). Generally, pseudo orthophotos are easier to generate since displacements of building roofs are not corrected. The tilted views of buildings and other structures of notable height remain unchanged so that the buildings' sides remain partly visible.

10.3. ORTHOPHOTO GENERATION

For accurate measurements, image mosaics and cross-referencing photos to other GIS data, it is necessary to generate orthophotos. The main features of an orthophoto are:

- compensation for the tilt of the aircraft;

- transformation of the central projection of the photo to an orthogonal projection including the correction of elevation-induced scale changes;

- if needed, orientation of the aerial photo towards north (rotation by 90° or 270°), because imaging flights are mostly done in either east-west or west-east direction, to minimize sun illumination effects.

10.3.1   Aerial photo and LOCATIONs preparation

If the aerial photo is available only on an analog medium, the diapositive, it needs to be scanned using a (photogrammetric) backlight scanner. To change a standard flatbed scanner to a backlight scanner a special device is necessary. High quality is important to avoid the introduction of internal image distortions.

The scan resolution during the scanning process determines the effective ground resolution. The required value for the scan software can be calculated from the averaged image scale (see above Equation 10.1). The scanning resolution is usually specified in dpi (dots per inch). The ground resolution R_g in relation to the photo map scale is derived from the scale number M and the scanning resolution R_s (first considered in centimeter) as follows:

$$R_g[cm] = \frac{M}{R_s[lines/cm]} \tag{10.3}$$

For example, we have an aerial photo with the average scale 1:10,000. The scale number is M = 10,000 cm accordingly. The desired spatial resolution on ground R_g for the aerial photo is 40 cm (raster cell width and length). After rearranging the Equation 10.3, the scan resolution R_s which has to be defined for the scanner software is calculated as:

$$
\begin{aligned}
R_s[lines/cm] &= \frac{M}{R_g[cm]} \\
&= \frac{10000}{40cm} = 250\frac{1}{cm}
\end{aligned}
\tag{10.4}
$$

$$
\begin{aligned}
R_s[dpi] &= \frac{M}{R_g[cm]} * 2.54\frac{cm}{in} \\
&= 250\frac{1}{cm} * 2.54\frac{cm}{in} = 635dpi
\end{aligned}
\tag{10.5}
$$

In our example, the scan resolution has to be set to 635 dpi to obtain an average ground resolution of 40 cm. It is important to know that a certain pixel resolution does not allow to recognize objects of the same size. An object always needs to be covered by several pixels to become recognizable.

Another decision has to be made about the desired color depth, e.g. whether 256 or more colors should be used. The amount of required disk space is increased accordingly; a standard aerial photo scanned at 1200 dpi with 24 bit color depth will need more than 300 MB per image. Once the scan procedure is done, an image processing software (e.g. gimp) should be used to ensure that the bright fiducial marks within the fiducial marks are well visible. A zoomed fiducial mark is shown in Figure 10.3. These marks are crucial for the image-rectification task. This test of visibility can be used to define the lowest acceptable scan resolution. While verifying the fiducial marks, it is useful to zoom-in and denote the parameters from the photo's annotation bar: aircraft altitude, (calibrated) focal length and the timestamp.

Generation of the georeferenced target LOCATION. In the process of orthophoto generation, the scanned and imported aerial photo is ortho-rectified into a georeferenced LOCATION. This LOCATION, containing the reference map and the DEM, has to be created first. The default resolution should be defined in respect to the final target ground resolution of the aerial photo(s). Further details about defining a LOCATION are given in Section 3.2. As mentioned above, it may be necessary to interpolate the DEM to a higher resolution, as shown in Section 5.3.4, in order to minimize unwanted displacements due to DEM resolution problems. Before leaving the projected LOCATION it is recommended to adjust the settings such as resolution and current region to the desired resolution and coordinates to enable GRASS to store the orthophoto accordingly.
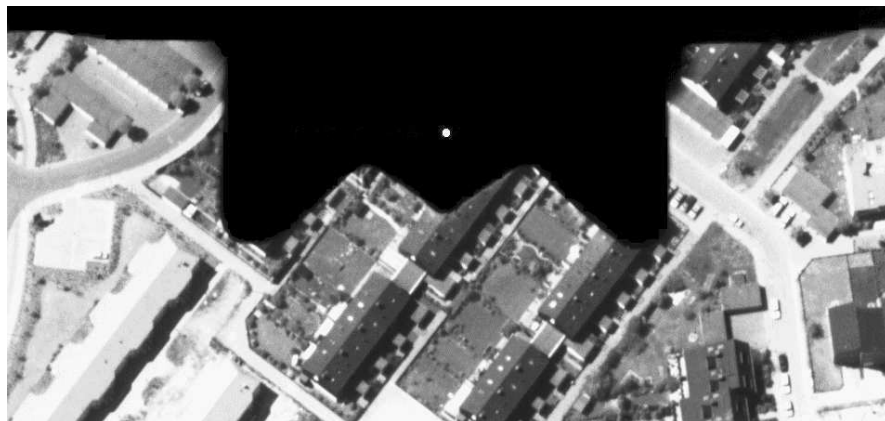

Figure 10.3. Zoomed fiducial mark in an aerial photo. The center of the bright point within the fiducial mark is used during the ortho-rectification process

Creation of the xy LOCATION for the scanned aerial photo.   You need to
restart GRASS to generate the xy LOCATION for the scanned aerial photo(s).
Multiple aerial photos can be imported into the same xy LOCATION. Be sure
to define the LOCATION large enough to hold the image(s). When importing
photos with `r.in.gdal`, this module optionally extends the current region if
needed (flag `-e`). The resolution is set to one pixel. Then you need to create
a separate image group for each aerial photo (see Section 9.3.2). Only in case
of multi-channel aerial photos you will add all channels in one group. For our
example, the xy LOCATION `imagery` is already available on the GRASS
Web site which we will use in this chapter.

10.3.2   Orthophoto generation from vertical aerial photos

The examples provided in this subsection are based on the aerial photos
available in the Imagery LOCATION. We will ortho-rectify the photo `gs13.1`
into the Spearfish LOCATION and also give additional tips for processing your
own data. For our example, the `gs13.1` photo, it is important to have an
appropriate high resolution elevation model available in the Spearfish LOCA-
TION. To create it from the existing map `elevation.dem`, you may restart
GRASS with this LOCATION, zoom into Spearfish city (located north-west
in the Spearfish region) and set the raster resolution to 1m. Now interpolate
the elevation model `elevation.dem` to the new resolution within the current
region.

Start the generation of orthophoto by restarting GRASS and entering the
demo xy LOCATION `imagery` with your name as MAPSET. Then gener-
ate an image group `aerial` with `i.group` and select the photo `gs13.1` as
member:

```
i.group group=aerial in=gs13.1
```

The GRASS orthophoto module incorporates several photogrammetric
tools. After opening a GRASS monitor, it starts with:

```
i.ortho.photo
```

If you have already generated the group `aerial`, it will be automatically
loaded. Otherwise, enter the previously created image group containing the
aerial photo. Then you reach the main menu:

```
i.ortho.photo --        Imagery Group = aerial

Initialization Options:

    1.      Select/Modify imagery group
    2.      Select/Modify imagery group target
```

```
   3.      Select/Modify target elevation model
   4.      Select/Modify imagery group camera

Transformation Parameter Computations:

   5.      Compute image-to-photo transformation
   6.      Initialize exposure station parameters
   7.      Compute ortho-rectification parameters

Ortho-rectification Option:

   8.      Ortho-rectify imagery files

RETURN   exit

>
```

We will use all menu items sequentially, except for menu item (6) which is required only for oblique aerial images (see Section 10.3.3) or for GPS-equipped flights. It is possible to interrupt the procedure between the steps and continue later; i.ortho.photo will store all settings.

1. Select/Modify imagery group. You have already completed this task when starting the module when you had to select a group. Check on top of the menu in the terminal window whether the appropriate image group is selected. If necessary, you can switch to another image group.

2. Select/Modify imagery group target. As a next step, the target LOCATION has to be selected. Enter the name of the projected LOCATION and MAPSET. This menu item corresponds to the module i.target (as discussed earlier in Section 9.4.1). For Spearfish enter spearfish as TARGET LOCATION and your name as MAPSET (if that MAPSET does not exist, you can use user1). To see a list of existing LOCATIONs or MAPSETs enter list into the related line.

3. Select/Modify target elevation model. Specify the name of the DEM which is stored in the target LOCATION. For Spearfish enter elevation.dem or the recently interpolated elevation model at a higher resolution.

4. Select/Modify imagery group camera. We will now define camera specific parameters. If you previously defined a camera within this MAPSET, you can load it. For our example, we enter the new name gscamera. Then the following screen appears:

```
       Please provide the following information:
+------------------------------------------------------------+
 Camera Name                                  DBA SYSTEMS CAMERA_
 Camera Identification                        _____
 Calibrated Focal Length mm.                  0_____
 Point of Symmetry: X-coordinate mm.          0_____
 Point of Symmetry: Y-coordinate mm.          0_____
 Maximum number of fiducial or reseau marks   0_____
+------------------------------------------------------------+
```

We enter the following parameters which belong to the photo `gs13.1` (in MAPSET `user1` you can find the camera parameters file `gscam` which belongs to the aerial photos `gs13.1` and `gs14.1`):

```
       Please provide the following information:
+------------------------------------------------------------+
 Camera Name                                  gscam_____
 Camera Identification                        gs-vqcy_____
 Calibrated Focal Length mm.                  152.41_____
 Point of Symmetry: X-coordinate mm.          0_____
 Point of Symmetry: Y-coordinate mm.          0_____
 Maximum number of fiducial or reseau marks   8_____
+------------------------------------------------------------+
```

Important parameters are the *Calibrated Focal Length* which is usually printed on the aerial photo (or delivered along with the aerial photo in a calibration report, for explanation see Section 10.1). The calibrated focal length is unique for each camera. In our example, the "gscam" focal length is 152.41 mm. The coordinates of the *Point of Symmetry* are kept zero since it is the origin for the image coordinates. If the camera data sheet provides different values for the *Point of Symmetry* than the ones provided by the manufacturer, they have to be specified. The number of fiducial marks can be seen on the aerial photo or taken from the photo accompanying camera description file. Four and eight fiducial marks are common. After leaving this screen by <ESC><ENTER> the screen for definition of the distances of the fiducial maps appears.

These distances are referring to the Point of Symmetry. The distance of the bright point inside the fiducial marks with respect to the point of symmetry has to be entered. The fiducial marks may be numbered as desired, but once defined, the numbering sequence must be kept identical to avoid reference errors from assignments of coordinates. If the calibration report defines the order, it should be used. Examples of photos with four or eight fiducial marks are given in Figure 10.4.

In a perfect 23 cm * 23 cm (9" * 9") aerial photo, the distance of the bright points is 113 mm from the point of symmetry. The distances depend on the camera type and will be provided by the camera manufacturer. According to the coordinate system, with its point of origin being set to the image center,

we define the following values for the `gs13.1` aerial photo (all values are in millimeters). You may start with the upper left fiducial mark (no. 1), the other marks are numbered clockwise, until we reach the middle fiducial mark on the left side (no. 8, compare Fig 10.4). The coordinates are entered accordingly:

```
      Please provide the following information:
+------------------------------------------------------------------+
       Fid#      Fid Id         Xf               Yf

         1        1_____      -106.01___       106.01_____
         2        2_____      0_____        106.01_____
         3        3_____      106.01____        106.01_____
         4        4_____      106.01____        0_____
         5        5_____      106.01____        -106.01___
         6        6_____      0_____        -106.01___
         7        7_____      -106.01___        -106.01___
         8        8_____      -106.01___        0_____

                    Next: end__
+------------------------------------------------------------------+
```

Now all required camera data are entered and we can go back to the main menu.

5. Compute image-to-photo transformation. Now we will establish the "interior orientation" of the image, which describes the relation between the physical extent of the aerial diapositive (in millimeters) and its pixels. The coordinate system is centered between the fiducial maps on the photo. The fiducial marks coordinates (as listed in the above table) are assigned to the fiducial marks in the image. This is done graphically in the GRASS monitor
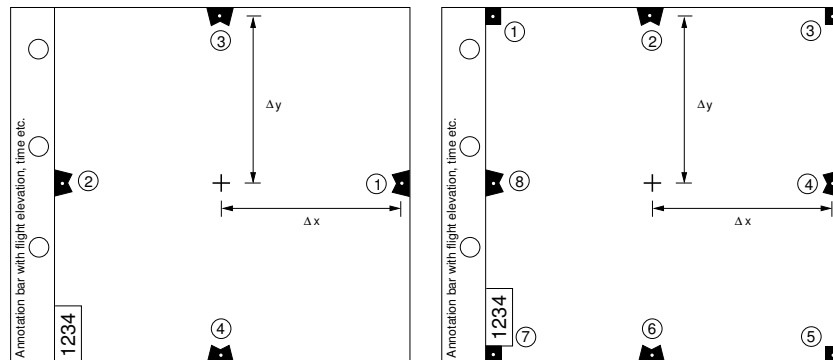

Figure 10.4. Fiducial marks in aerial photo. Left a variant with four fiducial marks, right a variant with 8 fiducial marks. The contents of annotation bar depend on the camera type

by mouse. It is important to refer the table entries carefully to the zoomed centers of the fiducial mark. Small deviations may case large errors in the "exterior orientation" that will be established later.

If the GRASS monitor is not open, you need to exit `i.ortho.photo`, open a monitor, and restart the `i.ortho.photo` module. After selecting this menu entry (no. 5), the aerial photo has to be selected in the monitor. The list of fiducial marks will be automatically displayed. The orthophoto module now expects the assignment of the fiducial coordinate points to the fiducial marks in the image by digitizing.

Using the "zoom" function, enlarge the first mark (mark 1 in the upper left corner of the `gs13.1` photo), until the bright point is visible as composed from multiple pixels. Generally, if no bright point is visible, the scanning resolution was set too low and you will have to start again from scratch by rescanning the aerial photo. In our sample data, the quality of the photo `gs13.1` is unfortunately very low, the fiducial marks in the corners are very difficult to identify. For now you may guess their position – this photo is from 1971, nowadays images are of course of much better quality. The center of the bright point within the enlarged fiducial mark is digitized using mouse by clicking into it. Then the related entry (row) in the fiducial marks table must be selected by double clicking on it. Now both image and fiducial marks coordinates are also shown in the terminal window. The marker in the GRASS monitor will turn to green color once the control point is accepted. This procedure has to be done for all fiducial marks.

The menu item ANALYZE in the monitor allows us to verify the digitizing accuracy. The RMS-error should be less than half pixel size. A misplaced point can be deactivated through a mouse double click on the corresponding control point in the ANALYZE table. This fiducial mark must then be re-digitized again. Once all fiducial marks have been successfully assigned to table entries, select QUIT to go back to the `i.ortho.photo` main menu.

We skip the menu step 6 as it is only needed for rectifying oblique aerial photos as described in Section 10.3.3.

7. Compute ortho-rectification parameters. Now we define the "exterior orientation" which relates the aerial photo to the target coordinate system using ground control points. Reasonable rectification results can be obtained with around twelve control points well distributed over the image. The related elevations, which are crucial for the creation of an orthophoto, are automatically read from the elevation data raster map that we have chosen earlier. To start, select again the aerial photo in the GRASS monitor for display. Then click on the "Plot Cell" entry and into the right part of the monitor to display the reference map. For the example session, you may again select the map `roads`.

Similarly to `i.points`, the corresponding control points are digitized by zooming into a map portion and digitizing the GCPs using mouse both in the aerial photo and in the reference map. When a ground control point pair has been marked in both the aerial photo and the reference map you have to confirm this with a new mouse click (left button: y, right button: n) as explained in the terminal.

Recommended control points are road intersection centers and the centers of objects (buildings etc.). However, be careful when using buildings. An aerial photo will show both the roof and the bottom of a building. Due to the central perspective in the unrectified image only the footprints of buildings may be used, not the displaced roofs. If you want to create a true orthophoto instead of a pseudo orthophoto, the DEM needs to contain the building heights. In this case, the building roofs have to be geocoded, so that both the buildings lower and upper edges are georeferenced.

When more than four GCPs have been digitized, their accuracy can be verified using the ANALYZE menu item. It displays a table of all control points with their RMS error. Each error value is calculated for the control points from the current transformation equations (depending on the camera type, etc). The value is computed for the target LOCATION, so it is given in the projection units of the target LOCATION (usually meters). If a control point appears heavily deviated according to the transformation equations, the row will be shown in red color. Such a control point can be deactivated by double clicking the entry in the ANALYZE table. The total RMS-error is acceptable if it is less than half target resolution of the aerial photo, e.g. below half a meter. Note that the RMS error significantly depends on the digitizing accuracy of the fiducial marks (see above, menu no 5).

If GCPs have been measured by other means, e.g. using a GPS, these coordinates should be entered. Each ground control point is marked within the aerial photo and then "KEYBOARD" is selected as an "input method" instead of the default "SCREEN". When sufficient number (twelve or more GCPs well distributed over the image) of ground control points have been digitized, you can leave the GCPs identification mode with "QUIT" and return to the main menu.

8. Ortho-rectify imagery files. Finally, the ortho-rectification process of the aerial photo can be performed by selecting the menu item (8). Enter a new name for the target orthophoto, in our example we will choose `gs13`. If several aerial photos have been stored in the image group (menu item (1)), they will be all listed here (e.g., multiband aerial photos). Because the defined control points are valid only for the current aerial photo, a new name for the target LOCATION for this photo will be entered here. After leaving this screen, the transformation equations are internally generated ("Computing equations...").

Then another query follows: Selecting "1. Use the current window in the target location" will start the rectification based on the settings in the target LOCA-TION. Selecting "2. Determine the smallest window which covers the image" allows us to override the settings in the target LOCATION from here, due to the image size and boundaries. The pre-defined values in this screen result from the current aerial photo and the ortho-rectification parameters. Eventually, the ground resolution should be modified to appropriate values and the photo boundaries should be extended to appropriate rounded coordinates.

GRASS will send an email when the rectification process is completed and the new orthophoto generated. Meanwhile, you can exit GRASS and perform other tasks on the computer. Once the email arrives, GRASS can be started with the target LOCATION to view and verify the new orthophoto. An overlay with the reference map will show the quality of the rectification.

10.3.3 Generating orthophotos from oblique aerial photos

The procedure is similar to the one described in Section 10.3.2, but we insert an extra step to take into account the flight and aircraft position parameters, that are needed to generate orthophotos from oblique aerial photos. This step is added after the computation of image-to-photo transformation.

6. Initialize exposure station parameters. In this step, the flight path parameters such as the aircraft tilt and crab, and the camera coordinates and altitude above sea level have to be defined (to be taken from aerial photo auxiliary data). The following three values for the camera position have to be specified (for an example see below):

- X: East aircraft position;

- Y: North aircraft position;

- Z: Flight altitude above sea level

Further the (approximate) tilt of the aircraft has to be specified. This is defined by the angles Omega (roll), Phi (pitch), Kappa (yaw). They represent (see Fig. 10.5, Hildebrandt, 1996:149, Schowengerdt, 1997:95):

- Omega (roll): Raising or lowering of the wings (turning around the aircraft's axis);

- Phi (pitch): Raising or lowering of the aircraft's front (turning around the wings' axis);

- Kappa (yaw): Rotation needed to align the aerial photo to true north: needs to be denoted as +90° for clockwise turn and -90° for a counterclockwise turn.
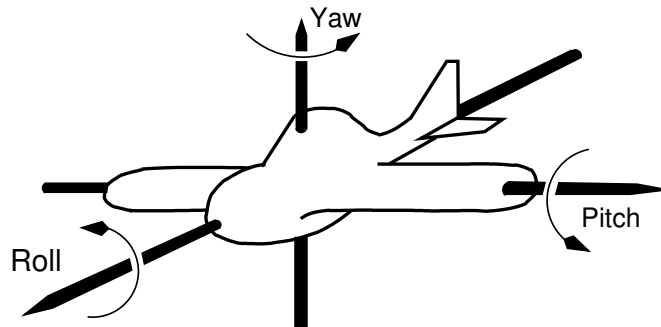
Figure 10.5. Attitude angles of an aircraft

Since Omega and Phi could only be guessed from the aerial photo's annotation bar (if present), approximate angles can be used. Only GPS-supported flights can provide these data accurately.

Then default values for the ortho-rectification calculations have to be entered, to provide initial values for the internal iterative computations. Appropriate value can be derived from the RMS-error. In our example, we set all X, Y and Z to 10 m. The question "Use these values at run time? (1=yes, 0=no)" we use "1":

```
        Please provide the following information:
+-----------------------------------------------------------+
 Initial Camera Exposure X-coordinate Meters:     593933__
 Initial Camera Exposure Y-coordinate Meters:     4926053_
 Initial Camera Exposure Z-coordinate Meters:     12192___
 Initial Camera Omega (roll) degrees:             0_____
 Initial Camera Phi (pitch)  degrees:             0_____
 Initial Camera Kappa (yaw)  degrees:             -90_____

 Apriori standard deviation X-coordinate Meters:  10_____
 Apriori standard deviation Y-coordinate Meters:  10_____
 Apriori standard deviation Z-coordinate Meters:  10_____
 Apriori standard deviation Omega (roll) degrees: 0.01_____
 Apriori standard deviation Phi (pitch)  degrees: 0.01_____
 Apriori standard deviation Kappa (yaw)  degrees: 0.01_____

 Use these values at run time? (1=yes, 0=no)       1_
+-----------------------------------------------------------+
```

Now the oblique camera position and additional initial parameters are defined, and we return to the main menu and continue with the step "7. Compute ortho-rectification parameters" and the subsequent procedure as described in the section above.

10.4. SEGMENTATION AND PATTERN RECOGNITION FOR AERIAL IMAGES

Aerial photos can be used for land use/land cover classifications similarly as the satellite data. However, because often only a single channel is available, either in black-and-white, in visible colors or in the infrared spectral range, the reclassification of aerial photos is different from satellite images. Image segmentation is a method for semi-automated feature extraction, such as the land use/land cover classes or edges from remote sensing data. A segmentation algorithm is implemented in the SMAP module `i.smap` which we already introduced in Section 9.8.3 for multi-channel satellite data.

The SMAP algorithm exploits the fact that nearby pixels in an image are likely to belong to the same class. The module segments the image at various scales (resolutions) and uses the course scale segmentations to guide the finer scale segmentations (image pyramid). In addition to reducing the number of misclassifications, the SMAP algorithm generally produces results with larger connected regions of a fixed class which may be useful in numerous applications. The amount of smoothing that is performed in the segmentation is dependent on the behavior of the data in the image. If the data suggest that the nearby pixels often change class, then the algorithm will adaptively reduce the amount of smoothing. This ensures that excessively large regions are not formed. The SMAP segmentation algorithm attempts to improve segmentation accuracy by segmenting the image into regions rather than segmenting each pixel separately.

The size of the submatrix used for segmenting the image has a principle function of controlling memory usage; however, it can also have a subtle effect on the quality of the segmentation in the SMAP mode. The smoothing parameters for the SMAP segmentation are estimated separately for each submatrix. Therefore, if the image has regions with qualitatively different behavior, (e.g., natural woodlands and man-made agricultural fields) it may be useful to use a submatrix small enough so that different smoothing parameters may be used for each distinctive region of the image.

Generating a training map. The module `i.smap` runs with single images as well as multispectral images. The raster polygons resulting from the segmentation process may be vectorized later with `r.poly`. To reclassify, `i.smap` requires a training map containing spectral signature. This training map contains numbered raster polygons which cover selected areas with homogeneous land use/land cover. The pixels inside a training area are considered to be spectrally similar. The training map is analyzed by `i.gensigset` which generates statistical information from the input aerial image based on the

training map. The training map can be digitized (`r.digit` or `v.digit` with `v.to.rast` subsequently). The image statistics derived by `i.gensigset` is input to `i.smap`. As opposed to the Maximum Likelihood Classifier algorithm which operates pixel-wise, the SMAP also considers spectral similarities of adjacent pixels. The module `i.smap` expects the aerial image listed in an image group and subgroup.

If the aerial photo is a color image, it may be analyzed in three channels. During import, a 24 bit aerial color image can be split into the red, green and blue channels. Also black-and-white images can be roughly split into three pseudo-color images with `r.mapcalc` (# operator, see Section 5.2). The # operator can be used to either convert map category values to their grey scale equivalents or to extract red, green, or blue components of a raster map layer into separate raster map layers. The # operator has three forms: `r#map`, `g#map` and `b#map`. These extract the red, green, or blue pseudo-color components in the named raster map, respectively. For example,

```
g.region rast=gs13
r.mapcalc "gs13.r=r#gs13"
r.mapcalc "gs13.g=g#gs13"
r.mapcalc "gs13.b=b#gs13"
d.rgb b=gs13.b g=gs13.g r=gs13.r
```

results in three pseudo-color channels which may be used for the segmentation. However, when working with 24bit images, the information contents is certainly higher.

Sometimes it is useful to generate and additionally use synthetic channels for the classification. For example, the module `r.texture` creates raster maps with textural features from image channels. The textural features are calculated from spatial dependence matrices at 0, 45, 90, and 135 degrees within a given moving window. For details, please refer to the related manual page.

A sample segmentation session. A sample segmentation procedure for the aerial image `gs13` which was previously ortho-rectified into the Spearfish LOCATION may be performed as follows:

```
g.region rast=gs13
i.group group=segment subgroup=segment in=gs13

#digitizing training areas such as fields, forest, roads etc,
#save as map "training":
r.digit
d.rast training

#generate class statistics from training map:
i.gensigset training gr=segment sub=segment sig=smapsig
```

```
#run segmentation:
i.smap gr=segment su=segment sig=smapsig out=gs13.smap
d.rast gs13.smap

#vectorization and visual./report of land use/land cover map:
r.poly -l in=gs13.smap out=gs13.smap
v.support gs13.smap
d.vect gs13.smap
v.report gs13.smap type=area units=h
```

Depending on the training map, the result can be a vectorized land use/land cover map. However, this map may contain a lot of spurious areas. These can be filtered with the script `r.reclass.area`. As an example, only areas greater than 0.25 hectares will be preserved (note, this script only operates in georeferenced LOCATIONS):

```
r.reclass.area -g 0.25 gs13.smap gs13.smap.filt
d.rast gs13.smap.filt
```

The deleted areas are filled with NULL (no-data) values. To reassign values to these NULL cells, we can use a mode filter which replaces the NULL cells by the dominating land use value in the 3x3 neighborhood. The mode filter is implemented in `r.neighbors`:

```
#mode filter to replace NULL cells:
r.neighbors gs13.smap.filt out=gs13.smap2 method=mode size=3
d.rast gs13.smap2

#vectorization:
r.poly -l in=gs13.smap2 out=gs13.smap2
v.support gs13.smap2
d.rast gs13
d.vect gs13.smap2 col=yellow

#area report:
v.report gs13.smap2 type=area units=h
```

We have now the land use/land cover map available as raster and vector map layers. Special care has to be taken for shadows resulting from sun which may either be treated as a special class or reduced by image pre-processing.