GENERATION OF TRUE ORTHOIMAGES FROM AIRBORNE SCANNER DATA WITHOUT THE NEED OF HEIGHT INFORMATION

J.Albertz, D. Bornemann, H. Zoberbier

Institute for Geodesy and Geoinformation Science, Technical University Berlin, Str. des 17. Juni 135
D-10623 Berlin, Germany - albertz@igg.tu-berlin.de

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ABSTRACT:

This paper presents a new technique for the efficient production of true orthoimages. The approach is based on airborne scanner data, and takes advantage of the particular geometric properties of such data. If scanner data are available, that are acquired in two flight lines perpendicular to each other, no height information is required to generate true orthoimages.In airborne pushbroom scanner systems one sensor line is looking to the nadir and is adjusted perpendicular to the flight track. The data acquired by the nadir channel follow a mixed geometry. In flight direction the mapped area is imaged in parallel projection. Across to the flight line the terrain is imaged in central projection. In other words, in flight direction, object points recorded are not displaced due to their height, but mapped in a correct position. On the other hand point displacements because of object heights occur only crosswise to the flight directions scene is imaged twice in flight lines perpendicular to each other, the first image strip provides correct ground coordinates of any object in one direction, the second image strip in the other direction. The new approach takes advantage of these particular geometric properties. It is based on the definition of corresponding points in the image data sets by means of matching techniques. Each conjugate point directly provides the correct ground coordinates and can be assigned as a pixel to the orthoimage. Thus, a true orthoimage is generated without any knowledge of the object heights or further calculations. The paper provides a detailed description of the approach, and its advantages and limitations are discussed.

1. INTRODUCTION

Traditionally differential rectification of aerial photographs is applied to generate orthoimages. This requires a height model to correct for the radial displacements, which are caused by the central perspectivity of the images. It is obvious that the quality of the product depends on the precision of the height model provided. It is common to use *Digital Terrain Models* (DTM) describing the topographical surface of the terrain. However, these models do not contain objects above the terrain surface, such as buildings, bridges etc. Therefore such objects cannot be corrected and rectified to their true position in the reference plane. In order to achieve improved results, objects above the terrain must be modeled in a *Digital Surface Model* (DSM). Utilizing such models it is possible to derive orthoimages with high objects in their correct position, thus the result is a "True orthoimage".

Many approaches have been developed to generate DSMs, e.g. from urban areas. But in any case it is a very time-consuming and cost-intensive procedure to generate such height models. In other words to provide these data remains the bottle-neck of true orthoimage generation.

In this paper we introduce a new approach for generating true orthoimages. It is based on digital airborne data, recorded with line-scanning cameras – so-called *Pushbroom Scanners* – and does not require any information about the height or geometry of the objects. Also, the paper presents the first results of recent research with real data from a line-scanning camera, the pre-processing of data, the assumptions and the achievable geometric accuracies.
The following section of this paper describes briefly the traditional approach of producing true orthoimages, its conditions, limitations and drawbacks.

2. THE TRADITIONAL APPROACH FOR THE PRODUCTION OF TRUE ORTHOIMAGES

It is common to generate orthoimages from aerial photo-graphs or from data acquired by digital frame cameras. Due to the central projection the acquired aerial photographs contain scale variations and especially radial relief displacements. In the process of differential rectification, digital elevation models are used to consider the effects of relief displacements. Therefore, orthoimages represent the terrain in parallel projection with a uniform scale and the relief in its true ground position.

However, objects above the relief surface or reference plane, like buildings, bridges, trees, etc. are usually not described in the used elevation model. Therefore such objects, mainly man-made objects, are displaced from their true ground position. The orthoimage is partly geometrically inaccurate and shows leaning buildings and bent bridges (e.g. Mayr, 2002). Some important ground features like footpath, streets and other objects are hidden for the user of the orthoimage. By applying the differential rectification approach for large-scale orthoimages over urban areas, also double mapped areas may appear. In other words, these orthoimages do not have the same characteristics as a map and it can be difficult to locate objects, compute areas, measure distances and obtain other useful information (Habib et al., 2007). The mentioned shortcomings make it difficult to integrate orthoimages as important components into a GIS database.

Consequently many attempts are being made to generate so called “True Orthoimages” as highest quality orthoimages. Related literature provides us with many interesting approaches for this purpose, but all require a detailed three-dimensional description of man-made objects in vector format, which is very difficult to achieve.

However, after the correction of the displacements, the remaining empty areas, so called gaps, must be filled up with image data from a corresponding imagery. The result of the described process is an orthoimage in high quality, a "True Orthoimage", which shows all objects in their correct ground position. The process of true orthoimage generation, the geometric conditions and new improvements are published in the literature, e.g. Habib et al. (2007), Kraus (2004), Mayr (2002).

Recent developments of optoelectronic line-scanning cameras allow an entirely new approach for orthoimage generation. The approach is based on the particular image geometry of the new camera systems. The next section demonstrates the specific feature of the image geometry and the background of the new approach

3. OPTOELECTRONIC LINE-SCANNING CAMERAS AND THE NEW APPROACH

In order to overcome the mentioned difficulties, a new approach for the generation of true orthoimages has been developed and presented for the first time by Albertz and Wolf (2004). The most interesting fact is, that this method does not require height information for true orthoimage generation. This is made possible through the development of optoelectronic line-scanning cameras. Such cameras, operating in the so-called pushbroom mode, consist mostly of three or more CCD-lines, which acquire image data from the terrain surface by the continuous forward motion of the camera system and constant reading of the CCD-signals. This method follows the three-line concept introduced by Hofmann (1982). In theses cameras one sensor line is facing to the nadir and is adjusted perpendicular to the flight track. Thus the data acquired by this channel show mixed geometrical properties. In flight direction the terrain is imaged in parallel projection and across to the flight direction in central perspective (Figure 1). Now, if ideal flight conditions are assumed, the displacements of objects due to its height occur only across the flight direction. This means that the same objects show no displacements along the flight direction and are located in their correct ground position. The most important aspect is that this result is independent from the height of the objects. These unique geometrical properties have never been used in the traditional generation of orthoimages.

Figure 1 shows a digital three-line scanner schematically. The overflown terrain will be imaged by the three sensor lines a, b and c, in the focal plane of the camera system. Under ideal flight conditions, the nadir-looking line b observes a differential line g of the terrain. Assuming a uniform forward motion along the flight line F and a constant recording rate, an image strip will be recorded showing the terrain in mixed projection. Relief displacements occur only along the line, so that the object H is leaned out within the line. But, a true ground coordinate exists in flight direction independent from the height of the object.

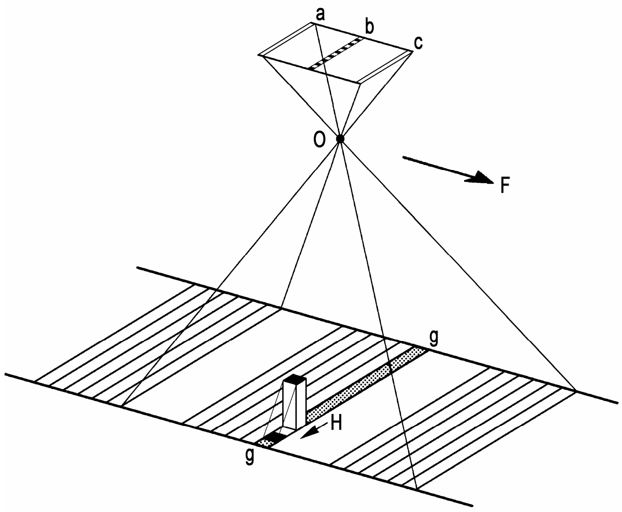

Figure 1. The principle of a three-line scanning camera

The new approach for the generation of true orthoimages makes use of this particular image geometry. However, this requires that the same terrain must be imaged twice, with the condition that the second flight line is oriented perpendicular to the first one. Consequently the direction, which was previously imaged in central projection, shows parallel projection in the second flight line, and thus provides the second ground coordinate.
Therefore, the basic idea of the new approach is to combine the two strips to produce data in parallel projection, i.e. true orthoimages, in one coordinate system. The principle is schematically illustrated in Figure 2.

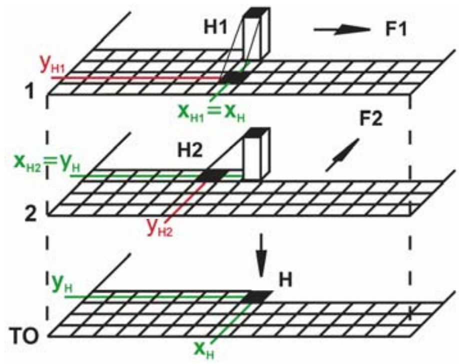

Figure 2. The combination of data from two flight lines to form a true orthoimage

The top level shows the object H with a specific height above the reference plane. The surface of the object is imaged at the position by flight line F1 and displaced across (1). The same surface is imaged towards the other coordinate direction by flight F2 and even displaced across (2). This means, correct ground coordinates exist in the flight directions. By combining the given coordinates, the image pixel or ground segment H can directly be mapped into the matrix of the true orthoimage plane (TO).

It is evident that the successful application of this approach depends on two conditions:

1. The geometrical assumptions must be fulfilled, i.e. the imaging plane must be vertical, and the flight lines must be

oriented perpendicular to each other. The effects of deviations from these requirements are discussed in section 4.

2. For the identification of corresponding image points effective matching techniques must be applied. This is discussed in section 5.

For both aspects practical experiments have been carried out. The test data have been provided by the Institute for Planetary Research, German Aerospace Center (DLR). They have been acquired in an aerial survey over an urban area with the HRSC-AX in combination with high-precision DGPS and INS. This camera system, developed for aircraft operation, has a scan line of 12,000 pixels (Scholten et al., 2002). The area was flown from south to north and from west to east (marked with arrows in Figure 3) in an altitude of approx. 3650 m above the ground. The ground sampling distance was approx. 15 cm. The data were already corrected radiometrically, and the orientation parameters were provided for each individual image line.

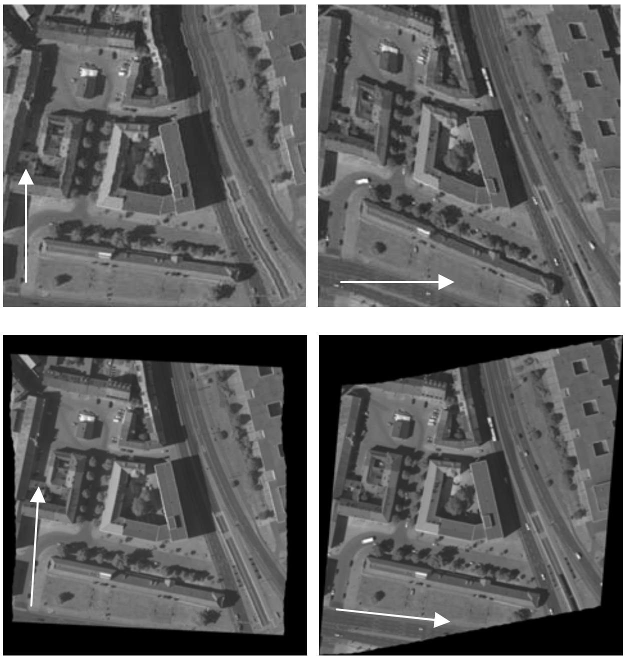

Figure 3. The pushbroom scanner data of a test area with the flight directions shown on top, in the left image from south to north, and in the right image from west to east. Below, the flight motion corrected image data.

4. GEOMETRICAL INVESTIGATIONS

4.1 First Geometrical Correction

From the images in Figure 3 it is clear that some geometric corrections are necessary before further processing. Due to the significant distortions in the raw data through aircraft motion and due to the deviations in position of the individual scan lines, the identification of corresponding points and the combination of the resulting ground positions could not be effective. Thus, the geometric distortions by aircraft motion must be corrected in a first step.

This correction can be achieved utilizing the internal and external orientation data of the camera, which is available for any scan line. The correction of the image data refer to a reference plane (Figure 3 lower images). Such a rectification process was first established by Wewel et al. (1998).

In this example the WGS84 ellipsoid was selected as the reference plane and the conformal UTM-projection with a locally defined middle meridian was applied. Due to the local UTM-projection and the small area, the influence of meridian convergence can be ignored.

The deviations from the ideal configuration are significant. It is evident from Figure 3, that the simple image geometry gets lost. This means that the flight direction must not coincide any more exactly with the direction, in which the objects are shown in vertical parallel projection. This has a direct effect on the new process for the generation of true orthoimages. The influences of the aircraft motions can be estimated with the sensor rotation angles roll, pitch and yaw. For the calculation the boresight angles between the INS and camera system were used (see Sandau, 2005). Figure 4 shows the calculated orientation angles as well as the variations in both flight strips, containing 13000 image lines.

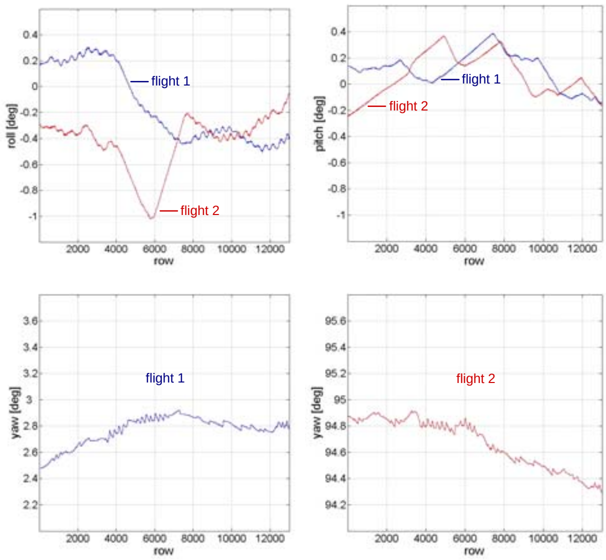

Figure 4. Sensor movements roll, pitch and yaw for both flight lines. Roll in the upper left, pitch in the upper right diagram. Yaw for flight 1 in the lower left, for flight 2 in the lower right.

4.2 Effects of Orientation Angles

It is obvious from Figure 4 that the orientation angles change from one image line to the next. In order to study the influences of these changes the effects are discussed individually.

The *pitch angle* is of special interest. It indicates the deviation out of the nadir direction, which has a constant effect on the complete line. The vertical parallel projection is changed to an oblique parallel projection. Thus, objects above the reference plane are displaced in adjacent lines dependent from the height of the objects. This relief displacement also yields an incorrect ground coordinate of an image point. As an example for both image strips: if an object height of 50 m is assumed and the pitch angle is 0,4 degrees the displacement will be 2 pixels or 0,3 m.

For the new approach the elimination of the pitch influence is difficult, because the effect depends on the height of the objects. That means, the higher objects stand out from the reference plane, the more precise navigation for the aerial survey must be carried out. If the pitch angles of the scan lines are close to zero then the displacements perpendicular to the line will be smaller and the true ground coordinates become more precise.

The *roll angle* shows relatively quick and sudden changes in the raw image data and in the diagram. However rolling affects the new approach rather less. Thus the image points are also shifted here, but along the scan line. The influence has its maximum on the margin of the image strip, and is also depending on the height of the objects. However, this does not cause problems for orthoimaging, because the final ground coordinates are taken only perpendicular to the scan line (in flight direction).

The *yaw angle* refers to the north direction, thus it is different in the absolute values for both flight strips (see Figure 4 below). In general the yaw angle effects an azimuthal rotation of the original scan line and leads to deviations in x- and y-direction. But the x-direction (perpendicular to the scan line) is more important, because in this direction the objects are shown in parallel projection. The differential changes of the yaw angle from scan line to scan line cause that the flight direction does not agree any more with the x-direction and that the x-directions of the original scan lines change in the corrected nadir image constantly, e.g. by a drift.

However, a constant x-direction is essential for the new ortho-imaging approach, because the correct ground coordinates are taken in this direction. If a constant x-direction is defined for one image strip, e.g. by an average yaw angle, angle differences appear in every line between constant and real x-direction. The angle differences lead to shiftings perpendicular to the scan line with a maximum at the margin of line. The shifting becomes too large and one gets incorrect ground coordinates, by processing the complete image strip with one average yaw angle.

To solve this problem a subdivision of the overlapping image range into smaller segments with other x-directions seems feasible to hold the influence by the deviation of the individual x-direction low. As an example, the images in Figure 3 have an extent of 1000 pixels and a maximum angle difference of 0.2 degrees. Thus the difference yields incorrect ground coordinates by 3 pixels at the end of the line.

The differences between the yaw angles of both flight strips contain also possible effects of deviations from the ortho-gonality between the flight lines. Also in this case the differences are not constant from line to line. The deviations have its maximum on the strip margin and the effects are along the flight line. For the image segment in Figure 3 a constant difference was defined, thus the general part of the deviations can be attached to the incorrect ground coordinates, by a rotation. For the data investigated an average deviation from the ortho-gonality was determined as approximately 1.7 degree. This leads to a correction of approximately 17 pixels across to the line.

4.3 Occluded Areas

A general problem of true othoimages are occluded areas behind buildings, bridges, etc. Rather sophisticated techniques must be applied to fill the resulting gaps in the images. The situation will be improved due to the mixed projection of pushbroom scanners, where relief displacements occur only in one direction. Theoretical studies show that through this effect occluded areas are significantly smaller in pushbroom datasets than in images acquired in central projection. That means, the necessary computations for the correction of occlusions and filling gaps in the true orthoimage will be reduced.

5. DEFINITION OF CORRESPONDING POINTS AND TRUE ORTHOIMAGE GENERATION

For general investigations about the realization of image matching with real image data the following simplifications were assumed:

- the data acquisition of the data occurred in nadir direction,
- the azimuthal orientation (yaw angle) of every scanned line corresponds to the middle flight direction.

Furthermore following preparations were carried out:

- geometrical and radiometrical corrected image data were used
- the averaged flight directions were fitted to the coordinate axis's so that the flight tracks were oriented in parallel with the respective axes of coordinates of the image coordinates system.

These preparations and simplifications enable a direct work in the scan lines and the determination of the correct coordinates from the image contents.

For an exhaustive allocation of both images a correspondence analysis must be carried out for every pixel of an image. For detection of corresponding points in the two data sets the proven process of the normalized cross correlation was applied. For every pixel it delivers a statistical value, which shows how well the grey scale value variation of the searched pixel and its environment agree with the respective pixel of the other flight strip. The value range reaches from -1 to +1, and +1 is 100% of correspondence, 0 is no correspondence and -1 indicates an inverted correspondence. For the investigation only correlation values were used by at least 0.6 for the allocation of an image point.

For the sizes of the template matrices, which contain the grey scale values of the examined pixel and its neighbors, values between 3x3 and 9x9 were selected. The correspondence analysis was carried out in both directions. Pixels from the first image was searched in the second one and vice versa. The grey scale values of the found points have been averaged. Because of the similarity of a many pixels often ambiguities led to wrong results. In order to minimize this effect the range to be examined (search matrix) must be limited.

In the direction of central projection, objects which will stand out from the reference plane became displaced. In Figure 5 the displacement of some points is sketched schematically for both flight directions. The displacement of a point increases with the distance from the flight line.

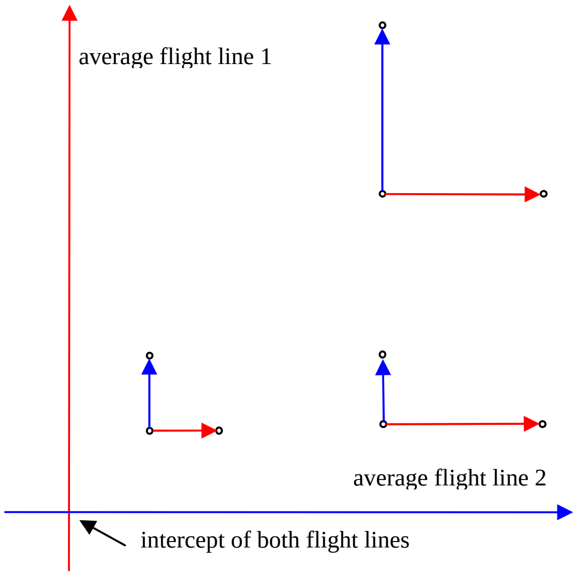

Figure 5: The displacement of object points above the reference plane referring to its position in terms of distance to the related flight line

The dislocation of a point depends on the height of the flight, the point height (distance from reference plane) and the distance of the point from the related flight line. The object height, the only unknown, is estimated roughly and is used to estimate the maximum displacements in order to optimize the range to be searched in. Thus, the ambiguities and the processing time get significantly smaller.

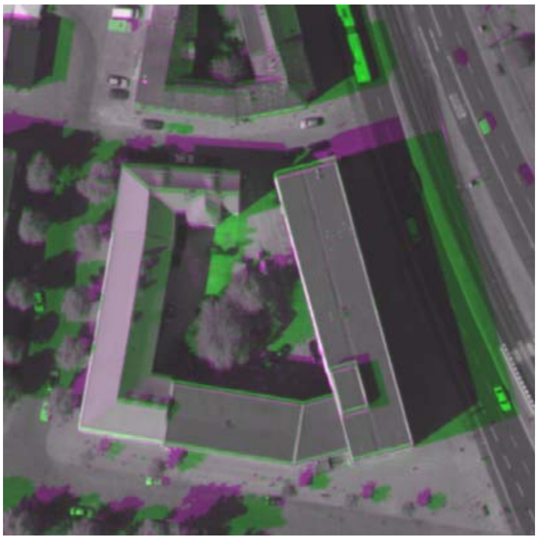

Figure 6: Fusion of the two input images

Figure 7: Median-filtered result of the correlation with template sizes from 3x3 to 9x9 pixels

In Figure 6 one can clearly recognize the displacement of building edges in vertical direction. In Figure 7 it can be seen how the double displayed building edges are corrected to one line. To close single missing pixels the result image has been filtered with a median filter of size 3x3. The ambiguities, which can't be excluded totally and the simplifications made in the beginning are the reasons for some loss of accuracy resp. sharpness.

6. CONCLUSIONS

The new approach for the generation of true orthoimages has been tested with real data. The simple image and recording geometry, which was earlier assumed in simulated studies, gets lost if real image data from an airborne pushbroom scanner are concerned. Several factors lead to variations from the ideal flight conditions. For this reason some pre-processing of the raw data is necessary. This prepares the basis for the determination of corresponding points and the extraction of true ground information.

A characteristic property of the data is the permanent change of orientation parameters for any scanned line. Related assumptions have been defined and corrections have been introduced. From the study it turned out that the image data was suitable, because only minor deviations from the ideal configuration occurred. Thus, the investigations of the geometry and the implementation of automatic correlation confirmed generally the practicability of the new approach.

However, more detailed studies and the development of effective matching procedures are necessary for future development. Then it can be expected, that the method offers a reliable and very productive alternative option to generate true orthoimages. Particularly, the independence from elevation models and the possible improvement of the visibility of occluded areas in certain urban regions are significant advantages.

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