

# GENERATING TRUE ORTHOIMAGES WITHOUT A 3D SURFACE MODEL

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## ABSTRACT:

It is the traditional procedure to generate orthophotos from aerial photographs by differential rectification. The effects of relief displacement are corrected by considering a Digital Terrain Model (DTM). Due to the fact that DTM's do not describe the surface of buildings, bridges, trees etc. such objects remain in perspective views in the resulting orthophotos. If a Digital Surface Model (DSM) describes the mentioned objects, the caused displacements can also be corrected, and the results are called "True Orthoimages". However, recent developments of optoelectronic cameras like HRSC or ADX 40 allow for a totally new approach for orthoimage generation. The nadir-looking channels of these cameras provide image data in parallel projection along the flight line, and in central perspectives across. If a 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 or corresponding areas by means of segmentation procedures. 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.

## KURZFASSUNG:

In der Regel werden Orthophotos aus Luftbildern mittels Differentialverzerrung gewonnen. Durch das Gelände bedingte Lageversetzungen werden mit Hilfe eines Digitalen Geländemodells (DGM) korrigiert. Da in einem DGM Objekte wie Gebäude, Brücken und Bäume nicht beschrieben werden, unterliegen diese im resultierenden Orthophoto weiterhin den zentralperspektiv bedingten Lageversetzungen. Digitale Oberflächenmodelle beschreiben die genannten Objekte, so dass die verursachten Lageversetzungen berücksichtigt werden können. Das Ergebnis wird „True Orthoimage“ genannt.

Die Entwicklung von optoelektronischen Kamerasystemen in jüngster Zeit, wie HRSC oder ADX 40, ermöglicht nunmehr eine völlig neue Verfahrensweise. Die senkrecht nach unten gerichteten Nadirkanäle liefern in Flugrichtung Bilddaten in Parallelprojektion und senkrecht dazu in Zentralprojektion. Wird eine Gegend zweimal in senkrecht zueinander liegenden Bildstreifen aufgenommen, liefert der erste Streifen lagetreue Koordinaten in einer Richtung und der zweite Streifen entsprechend in der anderen Richtung. Der neue Ansatz nutzt die Vorteile dieser speziellen Aufnahmegeometrie. Er basiert auf dem Auffinden korrespondierender Punkte in den Bilddaten mittels Bildzuordnung oder dem Auffinden homologer Flächen durch Segmentierungsverfahren. Jeder homologe Punkt liefert direkt lagetreue Koordinaten und kann als Pixel dem Orthoimage zugewiesen werden. Auf diese Weise entsteht ein „True Orthoimage“ ohne jegliches Wissen über Objekthöhen oder weitere Berechnungen. Der Beitrag gibt eine detaillierte Beschreibung des Ansatzes und behandelt seine Vor- und Nachteile.

## 1. INTRODUCTION

The traditional generation of orthoimages uses digital elevation models to consider the effects of relief displacements, which occur through the central perspective of photographs. Orthoimages, i.e. pictures in parallel projection, are derived from these photos by differential rectification methods. Objects above the surface, like buildings and bridges, are mostly not described in the used elevation model. Therefore such objects are distorted from their true position, and the orthoimage shows e.g. leaning buildings and bent bridges. Some interesting information from ground features like streets and other objects is hidden for the user of the orthoimage. Furthermore the superimposition of vector data is nearly impossible. This is why many attempts are made to generate so called "True orthophotos". All known approaches for this purpose require a detailed three-dimensional description of buildings etc. in vector format, which is difficult to achieve.

This paper will provide a totally new approach for generating orthoimages, which is based on digital airborne data recorded with optoelectronic line scanners, and does not require any information about the objects height or their geometry.

## 2. TRADITIONAL PRODUCTION OF TRUE ORTHOIMAGES

Digital terrain models (DTM), which describe the topographic surface geometrically, are so far generally used for the generation of orthoimages. It is well known, that objects not modelled in the DTM, particularly man made objects like buildings and bridges, are displaced in these procedures and are shown in a wrong position. The results of these displacements are e.g. leaning buildings and warped bridges. In order to improve the situation, Digital Surface Models (DSM) or Digital Object Models (DOM) describing the mentioned objects

geometrically, should be used, so that the displacements could be corrected straightforward. However, after the correction of the objects displacements there remain empty areas without any image information. These so called gaps necessitate filling up with corresponding data from other imagery. Then the result of the described process is a true orthoimage, which contains all objects in their correct position. The procedure and the geometric conditions are well understood and published many times in the literature, e.g. Mayr (2002), Braun (2003).

But to put this common knowledge into practice is very difficult, due to the fact that the data acquisition for detailed modelling of the objects above the topographic surface by photogrammetric methods is a very complex, sensitive and time-consuming task. Even new techniques like laser scanning methods could not solve the problem. However, a digital orthoimage is only as accurate as the surface model provided.

Through the development of optoelectronic pushbroom scanners a totally new approach for orthoimage generation became possible. It is based on the special geometry of the new camera systems, which should be shortly demonstrated.

### 3. PUSHBROOM SCANNERS AND THE NEW APPROACH

In principle the pushbroom scanners follow the three-line concept developed by Hofmann (1982). In general, there are three (or more) CCD-lines which acquire image data of the terrain surface continuously during the flight. At least one of the lines is nadir-looking and thus provides image data in parallel projection along the flight direction and in central perspectives across (fig. 1). This means that – ideal flight conditions assumed – the captured objects show no displacements and are provided in their correct position in flight direction. It is of particular importance that these results are independent from the object heights. These geometrical properties have never been considered in the traditional approaches for orthoimage generation.

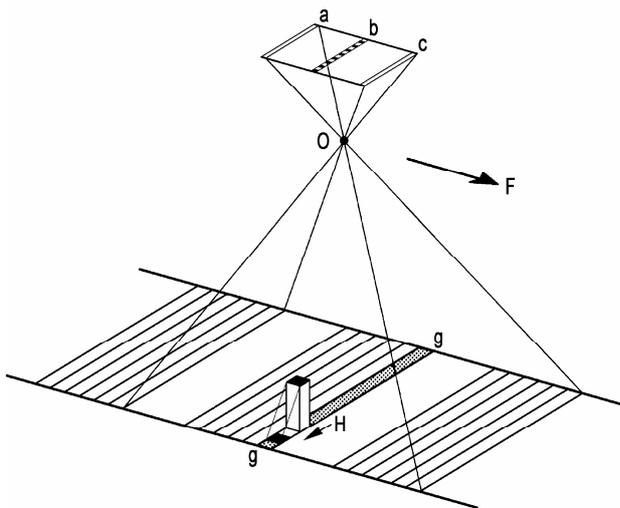


Figure 1. Data acquisition of a 3 line pushbroom scanner in principle

Now, the new approach makes use of this specific image geometry for producing true orthoimages. For this purpose, the surface must be imaged twice in two flight lines perpendicular

to each other. Thus, information about the correct location of any point is given in two directions. This fact is utilized by combining both data sets in order to derive data in parallel projection, i.e. true orthophotos. Figure 1 shows the digital airborne data acquisition by a 3 line scanner schematically. It is sketched, that the overflowed surface is imaged by three sensor lines a, b and c, located in the focal plane of the camera lens. Under regular flight conditions of the airplane the sensor line b observes a differentially narrow line g of the terrain surface. By a uniform forward motion of the acquisition system along the flight line F and a constant appropriate recording rate, a strip of image data will be recorded which presents the surface in parallel projection in flight line direction. Due to the fact that object displacements only occur along the sensor line, an object, e.g. a house H above the reference plane in figure 1, is leaned outwards in line direction. Thus, it exists a true ground coordinate value in the flight direction, and this is independent from the height of the object. This knowledge about the mapped points in flight direction wasn't used so far. As already mentioned, the new approach combines two strips in parallel projection in order to derive a pair of ground coordinates with correct values in both directions.

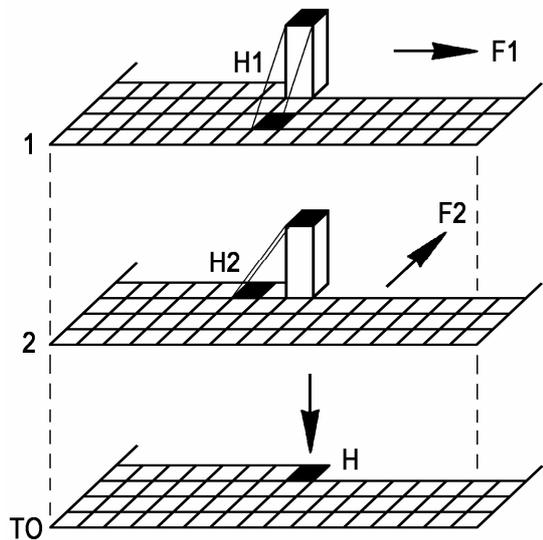


Figure 2. Schematic generation of the true orthoimage by means of the new approach

Figure 2 illustrates the main principles of the new approach. The surface of the illustrated object, which perhaps represents the roof of a building H, is imaged at position H1 by flight F1. At the second level in figure 2 the same surface is imaged towards the other coordinate direction by flight F2. By use of the given coordinates, the image pixel or segment H can directly be mapped into the matrix of the true orthophoto TO.

It is evident that the main issue in this approach is to locate corresponding points in both data sets and to connect them to the correct attitude information. This could be achieved in two different ways. The first one is the application of matching techniques as they are well established in digital photogrammetry (see e.g. Scholten et al. 1998, Wewel 1996). The second possibility for solving this task is making use of segmentation procedure in order to map corresponding image segments into the orthoimage. In this manner, the object displacements can be corrected with the knowledge of the proper location coordinates, and the final result will be a true orthoimage.

#### 4. EXPERIMENTAL TESTS WITH SYNTHETIC IMAGES

In order to verify the new approach, airborne pushbroom scanner image data were simulated. For this purpose an image sequence was acquired, and the medial rows of each image were cut out and finally merged to one dataset. Due to the fact that the swath angle of one row of a central perspective image is so small, parallel projection can be assumed in the final dataset. A parallelepiped solid was taken as the test object, because in this case the expected geometrical impacts are easy to understand, and can also readily be visualized. To provide photogrammetric analysis, a reference object was imaged together with the test object at the same time. Figure 3 shows the two objects from a perspective view. The reference object defines the object space coordinate system. In addition, two Cartesian coordinate axes were drawn in for a better visualization. The longer one indicates the x-axis and the shorter one the y-axis.

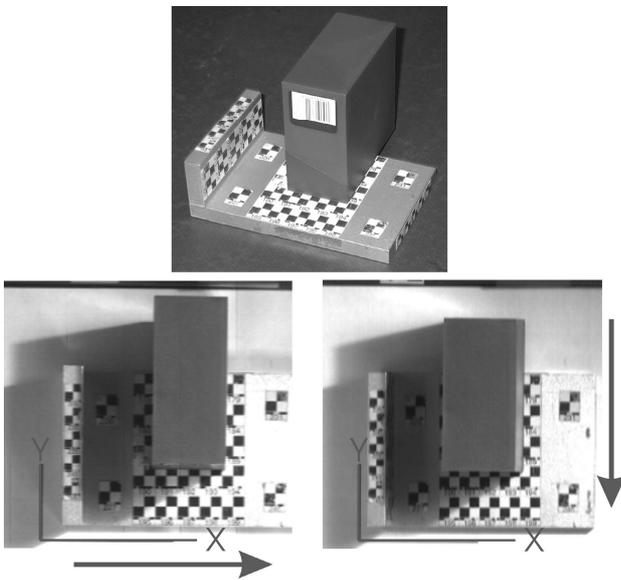


Figure 3. Perspective view of the parallelepiped solid together with the reference object, at the top. Below, the simulated pushbroom scanner data in x-direction (left) and in y-direction (right). The ground track of the two flight lines are marked by the arrows.

First of all, the objects were "overflow" in x-direction and the dataset was produced, as described before. In the lower left picture of figure 3, the parallel projection in x-direction is well visible, because there are no displacements left in flight direction, whereas the upper surface of the parallelepiped solid is dislocated in y-direction, as expected. The inverted distortions appear by the acquisition in y-direction, the displacements are solely x-directed in this case (lower right). The corner coordinates of the upper surface of the parallelepiped solid were measured in the next step and transformed from the image to the object space coordinate system. As explained earlier, there should be truly located x-coordinates in the simulated airborne pushbroom scanner image available in x-direction, respectively truly located y-coordinates in the image in y-direction. The combination of both information will result proper ground coordinates in x and y direction.

In order to establish geometric control of the results and to check this hypothesis, the measured coordinates were compared with coordinates calculated with traditional photogrammetric

methods. Therefore, a bundle block adjustment for the imaged reference object was accomplished with data from an array camera. Truly located three-dimensional coordinates were determined by a spatial intersection as a result of the bundle block adjustment. Thus, there exist no object displacements in these calculated coordinates. The result of the comparison is shown in figure 4. The round dots mark the points representing the measured coordinates derived by the new approach, and the squares show the points representing the coordinates as the result of the bundle block adjustment. The displacements in the two simulated scanner datasets are also shown in figure 4 as black triangles for the y-directed dataset and white triangles for the x-directed dataset. For example the difference between the filled triangles and the square points demonstrate the impact of the displacements in x-direction by flying towards y-direction. The four points around the reference object are control points for checking and for the calculation of the parameters like translation and rotation between the coordinate systems. The arrows in the right small picture in figure 4 illustrate the attitude of the camera relative to the observed objects.

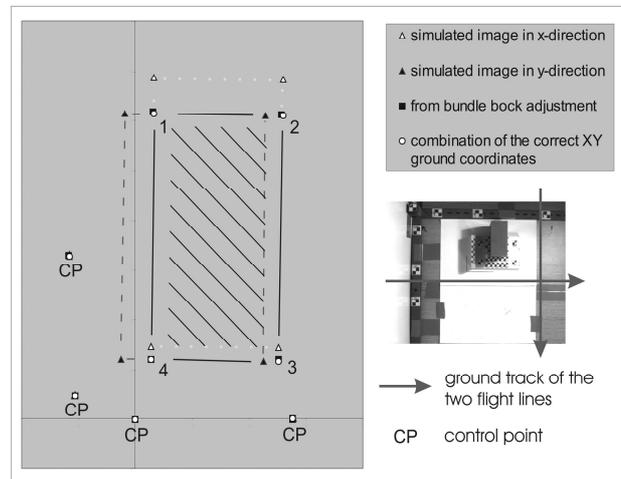


Figure 4. Result of the comparison between the coordinates obtained by means of the new approach and by bundle block adjustment.

The deviations between the measured coordinates and the ones calculated by bundle block adjustment are smaller than one pixel, and therefore in the accuracy of the measurement as expected.

#### 5. GENERATING TRUE ORTHOIMAGES

The experiment has shown the functionality of the new approach in principle. However, in order to meet the requirements of orthoimages, all points in the entire dataset have to be displayed in their correct position and not only the exemplarily shown outstanding points in figure 4. In order to achieve this area-wide, two methods can be applied which were already mentioned in section 3. The first possibility is finding corresponding points in both images by means of image matching algorithms. Many useful general algorithms for image matching have been developed so far, but due to the complexities of the imaged real world any method has also its shortcomings and yields insufficient results in particular situations. Therefore three basic reasons for such problems should shortly be explained. The first reason is, finding corresponding points is impossible, if an object point is located in a hidden area in one

image, because the conjugate point simply does not exist. Another problem is the ambiguity of object structures, because of the various possibilities for correlation in some cases false points are matched. Furthermore, in areas of low texture, matching homologue points becomes also impossible, because different positions in these areas can hardly be distinguished.

The mentioned problems are independent from the image acquisition system. Thus, the new approach has to deal with similar problems as they are common in digital photogrammetry. These problems are very much dependent from the objects properties, illuminations conditions, and from the structural image properties as well. To a certain extent improvements can be achieved by modifications of the data acquisition parameters, as e.g. the base-height ratio in conventional photogrammetry.

The second possibility for generating a true orthoimage is the segmentation of corresponding regions by means of automatic or manual procedures. It is evident, that also in this case the success is very much dependent from image characteristics. The application of automatic segmentation methods can only be effective, if the segmentation algorithms yield quasi identical segment contours in both image data sets. This can be achievable if roofs from buildings or other distinct geometric elements of man-made objects are concerned. In more complex situations, the image segmentation approach might fail. Detailed experimental studies and methodological improvements are necessary.

For a preliminary study, the manual segmentation was selected as described in the following. For this purpose, HRSC-AX pushbroom scanner images were used, which show a small part of a residential area, acquired in 4500 m flying altitude (fig. 5). This part was imaged in two directions perpendicular to each other. Hence, the requirements were fulfilled to generate a true orthoimage by means of the new approach. After the measurement of the area defining points in both datasets, in this case roof of the buildings, the correct ground corner positions were calculated by combining the coordinates from the parallel projected directions, in order to obtain the area locations in the true orthoimage. If coordinates of the area defining points exist in the two image strips, segments of the original image data can be mapped to the aimed true orthoimage, utilizing an appropriate transformation. For this purpose, the bilinear transformation was used, which is particularly suitable and practical for rectifying flat quadrangular areas, such as roofs etc. Such areas occur by a segmentation of any area that could be divided into triangles and quadrangles.

Figure 5 shows transformed roof areas of the buildings in their correct position, based on different datasets imaged from different directions. An entire roof was corrected, if it was completely visible in the image. In order to illustrate the manual segmentation in principle, the roofs of the imaged buildings were measured separately and the remaining features, e.g. tree-tops, were ignored. Due to the fact, that the roof areas were transformed into their proper ground position, gaps with blank content remained. This necessitates to fill them from the appropriate image. A correction of the radiometric variance and brightness values in the filled areas has to be calculated, due to the current demands on a true orthoimage. Anyway, it was not determined in this example, because of demonstrating the schematic correction by means of the manual segmentation method. Hence, the correction of roof areas in y-direction in an x-directed overflowed image is well visible, in the middle of figure 5.



Figure 5. At the top, part of a residential area imaged by HRSC-AX in x-direction. In the middle, corrected image in y-direction, based on a dataset imaged in x-direction. Below, corrected image in x-direction, based on a x-directed overflowed dataset.

The white gaps in figure 5 show the previous positions of these areas. The lower image shows the inverted case, correction in x-direction based on a dataset imaged in y-direction. In both cases the roofs are mapped in their correct ground position.

But, what are the pros and cons of the particular methods? Transforming a whole area is an important advantage of the segmentation method. Hence, new ground coordinates of each point in a partitioned area are calculated. Thus, the entire image could be transformed, if the segmentation should work for the whole image. In contrast, by image matching methods remain sporadic gaps of unconsidered points, if corresponding points were not found. However, truly located identical points occur in their correct ground position, therefore. By segmentation methods, a wrong partitioned area, which is not flat and contains significant height variances, appropriate displacements will remain. Another problem is the segmentation of confused structured areas such as treetops, which makes difficulties. The segmentation of a roof, even a more complicated one, is feasible, but searching flat area defining points of a treetop in two images is absolutely impossible. In this case, the image matching methods may provide a more suitable result.

The mentioned problems concern one special step in the procedure of the true orthoimage generation and don't affect the main principle of the new approach. The basic advantages are highly visible. The new approach doesn't require any information about heights of the imaged features or geometrical modelling of the objects. The digital orthoimages, which are generated with recent methods, are particularly influenced by several parameters. One of these factors is the geometrical resolution of the elevation model. The model needs to represent the object height variations, depending on the accuracy requirements of the final orthoimage, in order to rectify each feature to its proper position. Thus, the Orthoimage is as accurate as the digital elevation model. In general, the recent orthoimage generation methods directly depend on the support and also the quality from other data sources.

However, by means of the new approach, a true ortho image containing all features like buildings, bridges and trees in their correct grounded position, can be derived from the involved image data directly, without using information from other data sources. A further advantage of the new approach depends on the special geometry of the pushbroom scanner images. Removing the displacements leaves blind spots with blank content. Due to the fact that displacements in pushbroom scanner images occur just toward one direction, the resulting gaps are significantly smaller than in the traditionally acquired images by means of a metric aerial camera. The gaps can be filled to a large extent with information from the other appropriate image, because of the upright directed displacements. The mosaicking task to fill the gaps is at least easier than in traditional approaches.

Furthermore, the new approach provides multifunctional usability. Thus, the method is not only limited to aerial acquisition of terrain surface data, but it can also be used for capturing architectural facades etc. It just requires orthogonal data acquisition relative to the defining reference plane of the orthoimage in two directions perpendicular to each other.

## 6. CONCLUSIONS

The new approach for the generation of true orthoimages requires two sets of image data that have been taken with a linescanner system in two flight lines perpendicular to each other. Data acquisition must be carried out nadir-looking, i.e. in vertical planes, thus providing data in parallel projection along the flight lines and in perspective views across. If these ideal conditions are fulfilled, true orthoimages can be generated without any knowledge of terrain or object heights.

In order to derive an orthoimage from such data two different approaches can be applied, image matching and image segmentation. Preliminary studies have been carried out, and it was found, that both techniques offer some advantages, but both have also their limitations. Thus, more detailed investigations will be necessary, and especially combinations of both methods should be tested.

If a sophisticated and automated segmentation and matching procedure is carried out, the new approach can offer a reliable and very productive alternative option to generate true orthoimages. Particularly, the independence from elevation models and the coverage of other applications are significant advantages. However, for terrestrial applications special data acquisition systems have to be developed.

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