GENERATING TRUE ORTHOIMAGES FROM URBAN AREAS – A NEW APPROACH

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ABSTRACT:

Orthoimages are very important geospatial datasets, forming the database for a great variety of applications. So far, orthoimages are generated from aerial photographs by differential rectification to correct the effects of relief displacements. Digital Terrain Models (DTM) describe only the topographic surface but ignore trees, man-made objects, etc. Therefore, the effect of leaning buildings or bent bridges appears, especially in urban areas. Expensive Digital Surface Models (DSM) describe the entire surface including the mentioned objects. This enables the generation of orthoimages of a high quality which are called "True Orthoimage".
Now, recent developments of optoelectronic line-scanning cameras like HRSC or ADS 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 by combining the correct ground coordinates of each point. Thus, the generation of a true orthoimage becomes possible without height information. Due to the mixed projections of pushbroom sensor imagery, the relief displacements occur only in one direction. Thus, occluded areas are significantly smaller than in conventional aerial photographs. Moreover, the new approach takes advantage of the particular pattern of certain urban areas, to fill up remaining gaps with image information only from the participated image strips.

KURZFASSUNG:

Orthophotos sind sehr wichtige Geo-Daten, die als Grundlage für eine Vielzahl von Anwendungen dienen. In der Regel werden Orthophotos aus Luftbildern mittels Differentialentzerrung gewonnen, um die durch das Gelände bedingten Lageversetzungen zu korrigieren. Digitale Geländemodelle (DGM) beschreiben nur die topographische Oberfläche und nicht Bäume, künstlich geschaffene Objekte etc., was zu Effekten wie "liegenden" Gebäuden oder verzerrten Brücken führt. Teuere Digitale Oberflächenmodelle (DOM) beschreiben die gesamte Oberfläche einschließlich der genannten Objekte. Dadurch wird die Herstellung von Orthophotos hoher Qualität möglich, so genannte True Orthoimages.
Nunmehr ermöglicht die Entwicklung von optoelektronischen Kamerasystemen, wie HRSC oder ADX 40, eine völlig neue Verfahrensweise. Die senkrecht nach unten gerichteten Nadirkanäle solcher Kameras liefern in Flugrichtung Bilddaten in Parallelprojektion und senkrecht dazu in Zentralprojektion. Wird eine Gelände zweimal in senkrecht zueinander liegenden Bildstreifen aufgenommen, ergibt 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, indem die grundrisstreuen Koordinaten eines jeden Punktes kombiniert werden. Auf diese Weise ist die Herstellung von True Orthoimages ohne die Kenntnis von Objekthöhen möglich. Aufgrund der gemischten Projektionen von Pushbroom-Scannerdaten treten Lageversetzungen in nur einer Richtung auf. Deshalb sind verdeckte Flächen signifikant kleiner als in konventionellen Luftbildern. Darüber hinaus nutzt der neue Ansatz bestimmte Strukturen urbaner Gebiete, um die überdeckten Bereiche mit Bildinformation nur aus den beiden beteiligten Bildstreifen aufzufüllen.

1. INTRODUCTION

The traditional generation of orthoimages is based on digital elevation models to consider the effects of relief displacements that occur through the central perspective projection from height variations of the terrain onto the even image plane of a photograph. Orthoimages are derived from these photos by differential rectification methods. The acquired surface is shown in parallel projection after the correction. Man-made objects above the topographic surface, like buildings and bridges, are mostly not described in the elevation model applied. Thus, such objects are distorted from their true position, and the effects of leaning buildings and bent bridges occur. Some interesting information from ground features like streets and other objects in urban regions is hidden for the user of the orthoimage and its interpretability is decreased. Furthermore the superimposition of vector data is nearly impossible, which additionally limits the usability of orthoimages. This is why elevation models like Digital Surface Models (DSM) or Digital Building Models (DBM), which describe also the mentioned objects, ignored in a DTM, are necessary. The results of a rectification that base on such models are called true orthophotos. However, the generation of a detailed three-dimensional description is difficult and expensive.

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

more the new approach offers interesting advantages for acquisition of certain urban areas, with regard to lower relief displacements and object occlusions. It can be shown, that the new approach provides a better refilling of the gaps which occur through the correction of the relief displacements.

2. CONVENTIONAL GENERATION OF TRUE ORTHOIMAGES

The generation of orthophotos so far is generally based on Digital Terrain Models (DTM), which describe the terrain relief geometrically. It is well known, that particularly man-made objects like buildings and bridges are ignored in the DTM. Thus such objects are displaced and shown in a wrong position. In order to improve the situation, Digital Surface Models (DSM) or Digital Building Models (DBM), which describe also the man-made structures geometrically, are required, so that the displacements could be corrected straightforward. If no analysis of the visibility of the terrain close to buildings is carried out, this results in the effect of double mapped objects, which is called ghost image. To avoid this effect a hidden area detection has to be applied, Amahr et al. (1998) described a solution. However, empty areas without image information occur at the former position of the displaced objects after the correction and consideration of double mapped objects. These gaps have to be filled up with corresponding data from other imagery. Radiometric discontinuities along the fill-in boundaries have to be corrected by appropriate methods, e.g. histogram matching or weighted correction. The final result is called true orthoimage, which contains all objects in their correct ground position. The procedure and the geometric conditions are well understood and published many times in the literature, e.g. Mayr (2002) or Braun (2003). Many attempts are made to improve methods concerning hidden area detection, seamless mosaicking or enhancement of shadow areas.

However, all methods are principally based on height information and the digital Orthoimage is only as accurate as the surface model provided. But especially the data acquisition for detailed modelling of objects in urban areas by photogrammetric methods is a very complex, sensitive and time-consuming task. Even new techniques like laser scanning methods could not solve the problem.

3. PUSHBROOM SCANNERS AND THE NEW APPROACH

In general a pushbroom scanner consists of three or more CCD-lines which acquire image data of the terrain surface continuously through the forward motion of the camera system by means of airplanes or satellites. This method follows the three-line concept developed by Hofmann (1982). Pushbroom scanner imagery provides its data in a mixed projection, i.e. in parallel projection along the flight direction and in central perspectives across (fig. 1). If ideal flight conditions are assumed, displacements of objects, which are acquired from a nadir-looking line, occur only along the CCD-line. Thus, the objects are provided in their correct position in flight direction through the parallel projection. This effect is independent from the object heights.

Now, the new approach makes use of this particular geometry for the generation of true orthoimages. For this purpose the same surface must be imaged twice, with the second flight line

perpendicular to the first one. Now, the direction, which contains relief displacements before, is represented in parallel projection and therefore provides objects again in their non-displaced position. Thus, information about the correct location of any point is given in two directions of a coordinate system defined by the pushbroom scanner.
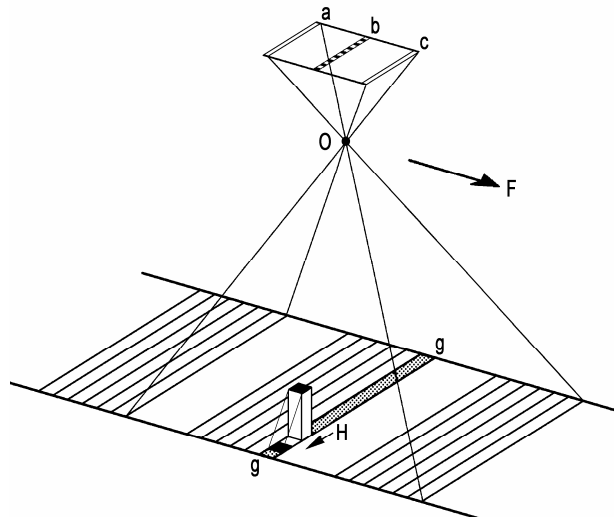

Figure 1. Illustration of the data acquisition with a 3 line pushbroom scanner

Figure 1 shows the digital airborne data acquisition by a 3 line scanner schematically. The overflown surface is imaged by three sensor lines a, b and c, located in the focal plane of the camera lens. The nadir-looking line b, that observes a differentially narrow line g of the terrain surface under regular flight conditions – horizontal attitude of the camera –, is of special interest for the new approach. Assuming a uniform forward motion of the camera system along the flight line F and a constant recording rate, an image strip will be recorded that presents the terrain surface in parallel projection in flight line direction and in central perspectivity across. Relief displacements occur only along the sensor line, therefore an object, e.g. a building H above the reference plane in figure 1, is leaned outward within the line. But independent from the height of the object, a true ground coordinate value exists in flight direction.

This knowledge about the mapped points in flight direction remained unused so far, but it forms the basis of the new approach. As already mentioned, the new approach requires two strips acquired perpendicular to each other to combine and derive a pair of ground coordinates with correct values in both directions. The main principles are illustrated in figure 2. The top level illustrates the data acquisition of the first image strip in flight line direction F1. The surface of the object, which perhaps represents a roof of a building H, is imaged at position H1 displaced across F1. Through the parallel projection the coordinate x_{H1} corresponds already with the correct ground coordinate x_H. The displaced value y_{H1} of position H1 must not be considered. The second level in figure 2 represents the imaged surface towards the other coordinate direction through the flight line F2. Thus, the coordinate x_{H2} corresponds with the y-axis of the first strip and with the correct ground coordinate y_H. That means, the image pixel or segment H can directly be mapped into the matrix of the true orthophoto TO by replacing y_{H1} with x_{H2} or inversely y_{H2} with x_{H1}. Either case leads to the correct ground position H.
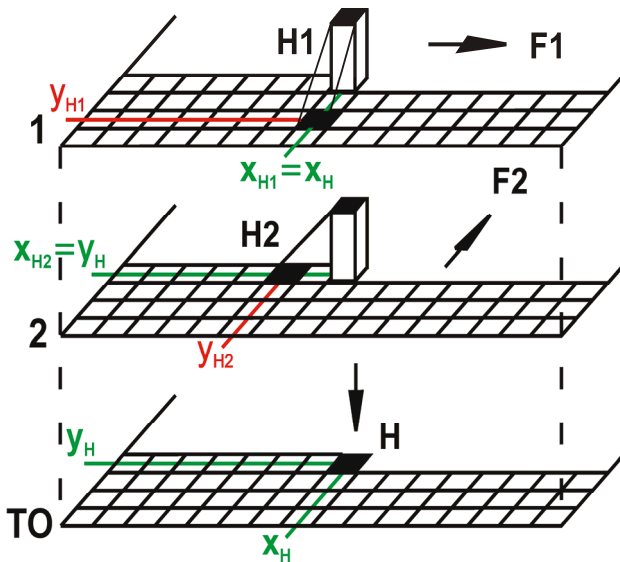
Figure 2. Scheme of the generation of the true orthoimage by means of the new approach

It is obvious that the main issue in this approach is to identify corresponding points in both data sets and to connect them to the correct attitude. Two different methods can be applied (Albertz et al. 2004).

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). An area-based matching algorithm detects corresponding points in the two image strips. Afterwards, the dislocated coordinate is replaced by the correct one as described. According to the used matching method, e.g. least squares matching, a determination with sub-pixel accuracy can be achieved. But all general useful algorithms have also their shortcomings due to the complexity of the imaged real world. Some particular situations yield insufficient results. For instance, finding corresponding points is impossible, if an object point is located in a hidden area in one of the images, because the second point simply does not exist. Other problems are ambiguities of object structures and areas of low texture, which lead to mismatched points, if a correlation is even possible. The mentioned problems are well known and are similar to problems in other procedures in digital photogrammetry. They depend strongly on the objects properties, illumination conditions as well as structural image properties and are not related to the acquisition system.

The second possibility for generating a true orthoimage is the segmentation of corresponding regions by means of manual or automatic procedures in order to map corresponding image segments into the orthoimage instead of single points. The automatic segmentation and allocation of corresponding regions can be achieved by feature-based matching techniques. The reliability and accuracy also depends on the image characteristics as mentioned at the point matching procedure. An interactive refinement by an operator is a very time-consuming task but still necessary if the automatic method fails.

In both procedures, the object displacements can be corrected with the knowledge of the proper location coordinates of the region defining points and the correct ones in the orthoimage through an appropriate transformation. The final result will be also a true orthoimage.

4. EXPERIMENTAL TESTS WITH SYNTHETIC IMAGES

In order to verify the theoretical knowledge of the new approach, airborne pushbroom scanner image data were simulated. For this purpose an image sequence was acquired with a digital array camera, and the medial rows of each image were cut out and finally merged to one dataset. Parallel projection can be assumed in the final dataset, due to the very small swath angle of one row of a central perspective image. To visualize the expected geometrical impacts readily, a parallelepiped solid was taken as the test object. 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.
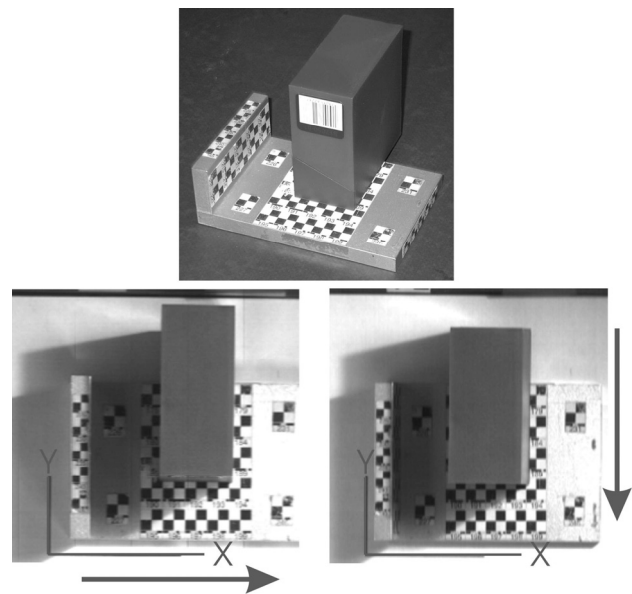

Figure 3. Perspective view of the parallelepiped solid together with the reference object, at the top. Below, the simulated pushbroom scanner data in x-direction (left) and in y-direction (right). The ground track of the two flight lines are marked by the arrows.

The lower pictures of figure 3 show the result of the synthetic pushbroom data generation. 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 (lower left picture). The inverted distortions appear by the acquisition in y-direction (lower right). In this case, the displacements are solely x-directed. In the next step the corner coordinates of the upper surface of the parallelepiped solid were measured and transformed from the image to the object space coordinate system. There should be correct located coordinates in the flight direction of the two simulated image strips and therefore available in the both direction x and y of the coordinate system, as explained earlier. The combination of this information will result proper ground coordinates for each point.

In order to check the hypothesis of the new approach, the measured coordinates were compared with coordinates calculated with a traditional photogrammetric method, using images from the array camera. Thus, a bundle block adjustment was accomplished for the imaged object. As a result of the bundle block

adjustment, truly located three-dimensional coordinates without displacements were determined through a spatial intersection. The result of the comparison is shown in figure 4.

The circular dots represent the points derived by the new approach, and the squares represent the points 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 instance 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.
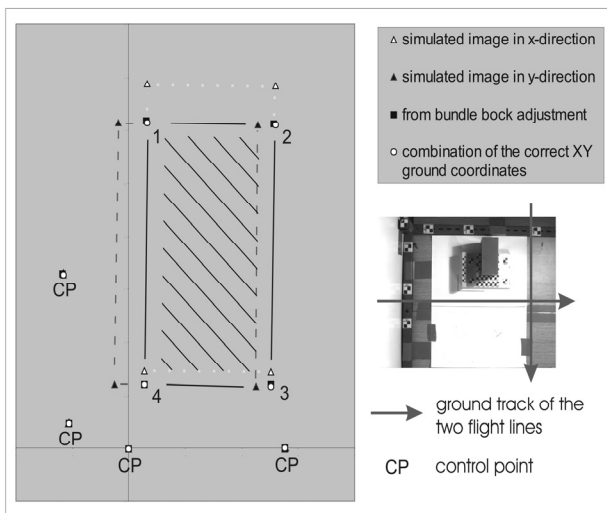

Figure 4. Result of the comparison between the coordinates obtained by means of the new approach and by bundle block adjustment.

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 AND ADAVANTAGES FOR URBAN AREAS

The experimental study has shown the functionality of the new approach in principle. However, 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. To solve this task, two methods can be applied, image matching and segmentation, which are described in section 3.

Due to the image characteristics and for preliminary studies, the manual segmentation was selected as described in the following. The area defining points were already measured in both data sets; therefore coordinates were available in the aimed orthoimage and the distorted position. Hence, the segment of the original image data can be mapped to the 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 areas occur by a segmentation of any area that could be divided into triangles and quadrangles.
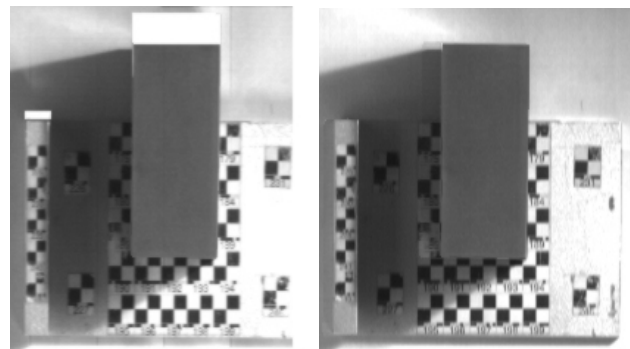

Figure 5. True orthoimages derived from the synthetic pushbroom data. Left, corrected image in y-direction, based on a dataset imaged in x-direction. Right, corrected image in x-direction, based on a y-directed imaged dataset.

Figure 5 shows the transformed surface of the imaged test and reference object in their correct position, based on the synthetic datasets. Due to the correction of the displacements, gaps with blank content remain at the former position (left picture). This necessitates to fill them from the appropriate image. This was achieved in the image acquired in y-direction (right picture). A correction of the radiometric variance and brightness values in the filled areas has to be calculated e.g. by means of histogram matching, due to the current demands on seamless orthomosaics. Anyway, the radiometric differences between the image strips were not smoothed out in this example, because of emphasizing the filled area, which is still visible.

This very simple example demonstrates some advantages, which depend on the acquisition system as well as on the specific acquisition conditions of the new approach. Due to the mixed projection of pushbroom scanners, relief displacements occur only in one direction. Empirical studies carried out show that the displaced areas are significantly smaller in pushbroom datasets than in images acquired in central perspective, with a probability of 60%. That means, the necessary computations for the correction of displacements and for filling the gaps could be reduced. Furthermore, the new approach enables the almost complete correction of occluded areas under certain conditions of the acquired objects, which should be discussed in the following. The test and reference objects in the experiment have a rectangular outline. Due to the data acquisition parallel to the edges of the objects, the hidden regions of the first strip are completely visible in the second strip and can therefore be corrected. Traditional procedures require at least 3 images and a higher effort in order to achieve a similar result.

Figure 6 shows a section of a down town area. The alignment and structure of buildings and streets is typical for cities in the USA. The partly high buildings occlude adjacent streets and in some cases also close-by buildings. The recent methods require a lot of images, great efforts and especially a detailed DSM to generate a true orthoimage from such an area. The final product will probably contain incomplete filled gaps due to the fact, that the occlusions were not visible completely in the participated source images especially in regions with a high density of tall buildings. But these buildings can be approximated and generalized as shown in the synthetically produced dataset due to their

mostly angular form. That means a nearly complete replacement of the distorted segments should be possible including the correction of the hidden areas with only two image strips similar to the described experiment above. A filling of the gaps fails only in such cases where a wall of a building is not parallel to the flight line direction, relief displacements could not be corrected or where the height distance ratio between adjoining houses yields occlusions of the same area in both images.

Figure 6. Section from a down town area, which shows a regular structure as it is typical for many US cities.

Unfortunately the described considerations are of theoretical nature so far, because real pushbroom data of the desired areas acquired under the related conditions were not yet available. But the experimental study with the simple solid already demonstrates the potential of the new approach, although the suggestions have to be verified.

The basic advantages are quite obvious. The digital orthoimages, which are generated with conventional 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 only 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. The new approach doesn't require any information about heights of the imaged features or geometrical modelling of the objects. Thus, a true orthoimage containing all features like buildings, bridges and trees in their correct ground position, can be derived from the involved image data directly, without using information from other data sources. Furthermore, if the theoretical suggestions could be proved, the new approach can be very useful for applications that require a good and complete visibility of the streets in regions with a structure mentioned above.

6. CONCLUSIONS

The new approach for the generation of true orthoimages requires two sets of image data that have been taken with a line-scanner system in two flight lines perpendicular to each other. The nadir-looking acquired information, i.e. in vertical planes, provides data in parallel projection along the flight lines and in perspective views across. True orthoimages can be generated without any knowledge of terrain or object heights, if these conditions are fulfilled.

Two different approaches can be applied, image matching and image segmentation, in order to derive an orthoimage from such data. Preliminary studies have been carried out with synthetic images, which simulated real pushbroom scanner data. These experiments confirmed the basic practicability of the new approach. Furthermore, advantages for urban areas have been discussed in these studies. Because of its theoretical nature, more detailed investigations are necessary in order to verify the results with real pushbroom scanner data and to test especially a combination of image matching and segmentation.

If the results could be proved and a sophisticated and automated segmentation and matching procedure is implemented, the new approach can offer 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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