GENERATING TRUE ORTHOIMAGES FROM URBAN AREAS WITHOUT HEIGHT INFORMATION

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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 in order to correct the effects of relief displacements. Digital Terrain Models (DTM) describe the topographic surface but they ignore trees, man-made objects, etc. Therefore, effects of leaning buildings or bent bridges appear, especially in urban areas. Detailed and 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 Orthoimages«.

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 any height information. Furthermore, due to the mixed projections of pushbroom sensor imagery, the relief displacements occur only in one direction, and therefore occluded areas are significantly smaller than in conventional aerial photographs. And the new approach can also take advantage of the particular pattern of certain urban areas, which makes it easier to fill up remaining gaps with image information.

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 image plane of a photograph. Orthoimages are derived from these photos by differential rectification methods. After this corrections the imaged terrain is shown in parallel projection. Man-made objects above the topographic surface, like buildings and bridges, are mostly not described in the elevation model applied. Thus, such objects are displaced 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 again 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 that are ignored in a DTM, are necessary. The results of a rectification process based on such models are called »true orthophotos«. However, the generation of the required detailed three-dimensional description is difficult and expensive.

This paper introduces 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. Furthermore 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.

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, so called ghost images. To avoid this effect a hidden area detection has to be applied (iii) 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, which contains all objects in their correct ground position, is called »true orthoimage«. The procedure and the geometric conditions are well understood and published many times in the literature (e.g. vi, iv). 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 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.

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 (v). Pushbroom scanner imagery provides its data in a mixed projection, i.e. in parallel projection along the flight direction and in central perspectives across (Figure 1). If ideal flight conditions are assumed, displacements of objects, which are acquired by 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 proper position. Thus, information about the correct location of any point is given in two directions of a coordinate system defined by the flight lines.

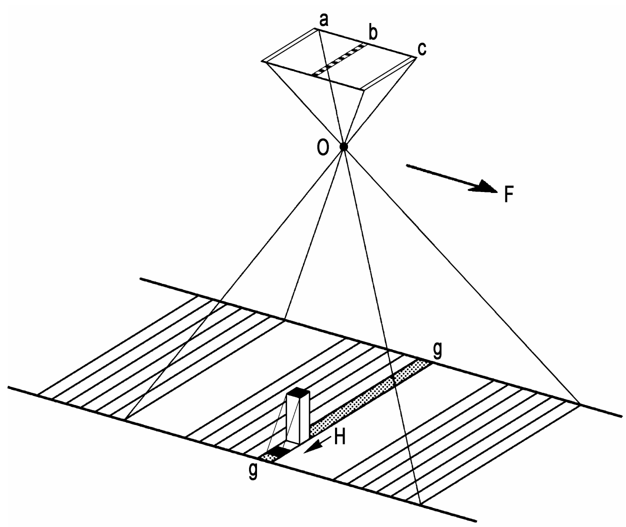

Figure 1: Illustration of data acquisition with a three-line pushbroom scanner.

Figure 1 shows the digital airborne data acquisition by a three-line scanner schematically. The overflown terrain 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 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 portrays 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 be combined in order to 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.

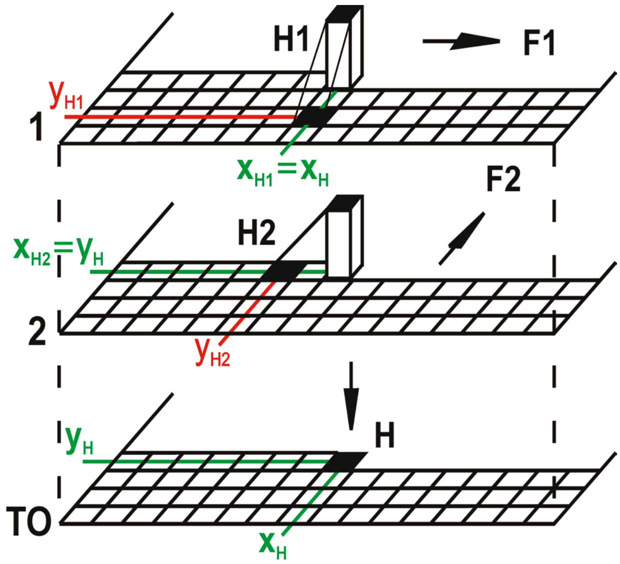

Figure 2: Scheme of the generation of the true orthoimage by means of the new approach

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 (ii).

The first one is the application of matching techniques as they are well established in digital photogrammetry (see e.g. vii, viii). 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.

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 a test object. To provide photogrammetric analysis, a reference object was imaged simultaneously with the test object. Figure 3 shows the two objects in a perspective view. The reference object defines the object space coordinate system.

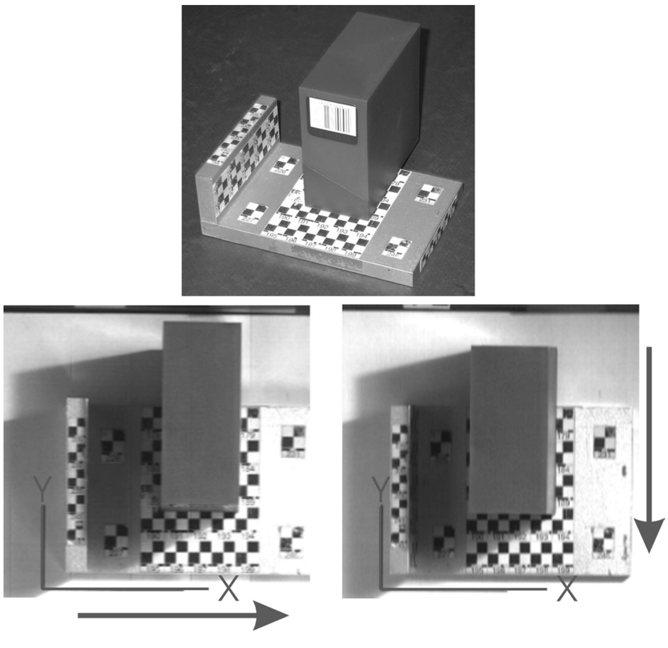

Figure 3: Perspective view of the parallelepiped solid together with the reference object, at the top. Below, the simulated pushbroom scanner data in x-direction (left) and in y-direction (right). The ground track of the two flight lines are indicated by the arrows.

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, as explained earlier. The combination of this information will result in 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 igure 4 illustrate the attitude of the camera relative to the observed objects.

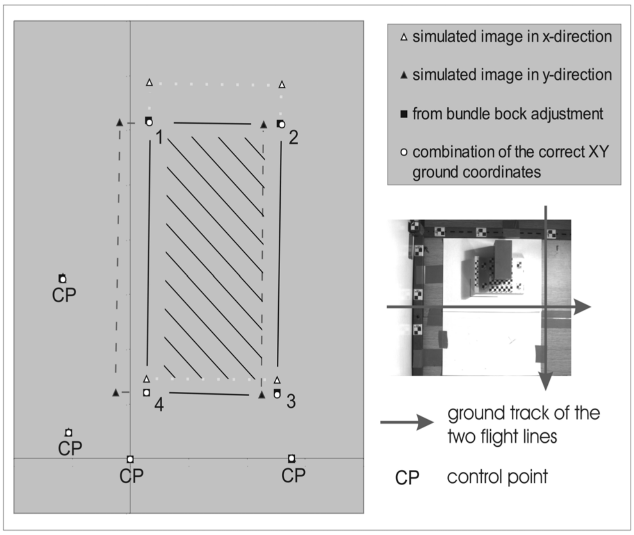

Figure 4: Result of the comparison between the coordinates obtained by means of the new approach and by bundle block adjustment.

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.

GENERATING TRUE ORTHOIMAGES AND ADVANTAGES 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, as already 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 applied, 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 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.

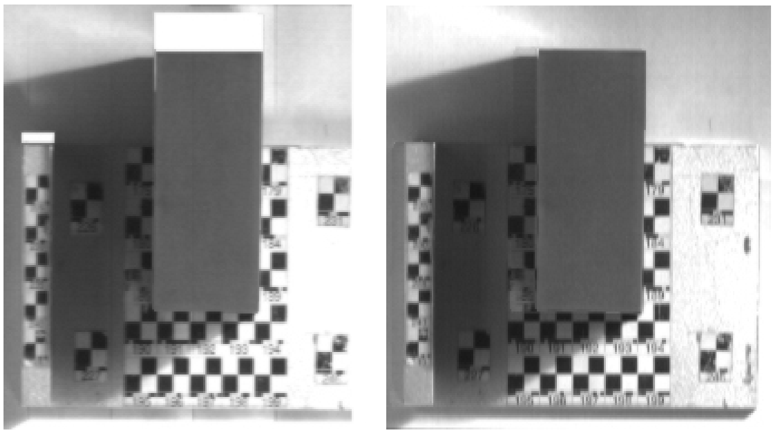

Figure 5: True orthoimages derived from the synthetic pushbroom data. Left: corrected image in y-direction, based on a dataset imaged in x-direction. Right: corrected image in x-direction, based on a y-directed imaged dataset.

This very simple example demonstrates some advantages, which result from the specific data acquisition conditions of the new approach. Due to the mixed projection of pushbroom scanners, relief displacements occur only in one direction. Theoretical studies carried out show that the displaced areas are significantly smaller in pushbroom datasets than in conventional images acquired in central perspectivity. 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 imaged objects. 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 three 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 many cities, e.g. in the USA. The partly high buildings occlude adjacent streets and in some cases also close-by buildings. The recent methods require many 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 participating images especially in regions with many high 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. Filling of the gaps fails only in such cases where a wall of a building is not parallel to the flight line direction, or where the height distance ratio between adjoining houses yields occlusions of the same area in both images.

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 and accuracy 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 proven, 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.

Figure 6: Section from a down town area, which shows a regular structure as it is typical for many cities, e.g. in the United States.

So far only very preliminary experiments with real pushbroom data, acquired under the related conditions, could be carried out. From a residential area crosswise acquired data were available from overflights with the High Resolution Stereo Camera (HRSC). The segmentation approach was applied by means of manual segmentation. Thus, the correct ground position of the roofs could be determined without knowledge of the heights (Figure 7).

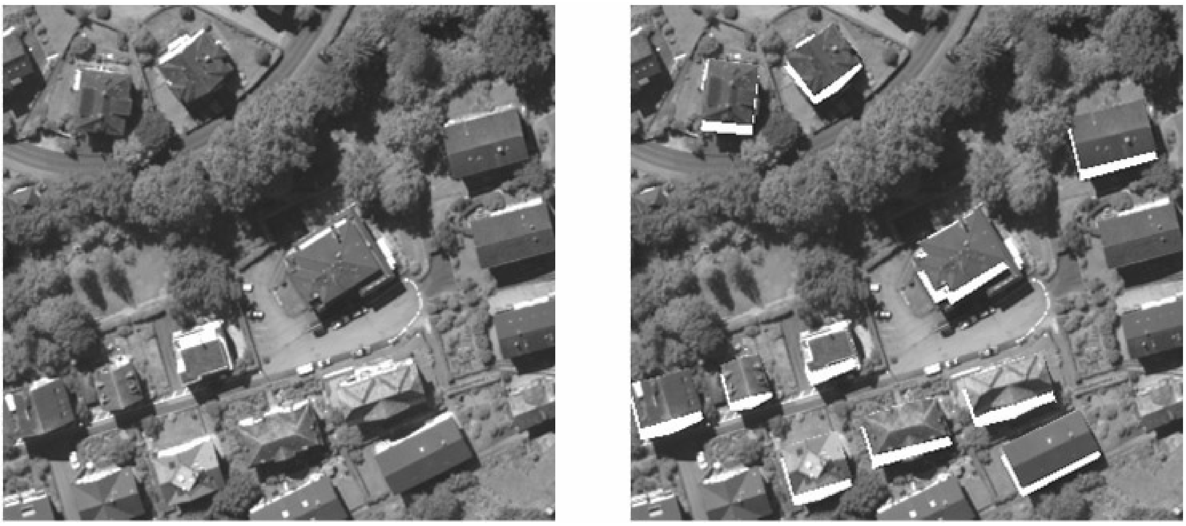

Figure 7: First experimental result from HRSC data acquired over a residential area. Left: Part of one set of the original image data. Right: The same data with the roofs corrected to their true position after manual segmentation.

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. 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.

However, the main issue of this technique is the identification of point and segments in the data. Two different approaches can be applied, image matching and image segmentation, in order to derive an orthoimage by this approach. 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 proven 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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