ONLINE-PROCESSING OF STEREO DATA OF CCD LINE SCANNERS

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ABSTRACT

There are two main reasons for a data processing concept allowing an automatic processing of image data of CCD sensors without operators into different products, e.g. digital terrain models.
The first one is that there are a lot of data sets that have to wait too long for their processing, because of the enormous man power needed. So an automatic processing of the raw data into any product is desired.
The second reason is that onboard processing of image data is possible with the use of digital CCD sensor systems instead of common analog cameras and devices for the determination of position and attitude. The image and the attitude data are available during the flight already, so all processing can be done close to the data source.
The processing concept introduced here is designed for CCD line scanners and enables a sequential data processing of the images.

KURZFASSUNG

Es gibt zwei Hauptbeweggründe für ein Datenverarbeitungskonzept, das die automatische Verarbeitung von Bilddaten von CCD-Sensoren ohne Operator bis hin zu verschiedenen Produkten, z.B. digitalen Geländemodellen, ermöglicht.
Der erste ist, daß es viele Datensets von Fernerkundungssensoren gibt, die zu lange auf ihre Prozessierung warten müssen, da enorme menschliche Kapazitäten eingesetzt werden müssen. Eine automatische Verarbeitung der Rohdaten zu einem Endprodukt wäre wünschenswert.
Der zweite Grund ist, daß mit der Nutzung von digitalen CCD-Sensorsystemen anstatt der analogen Aufnahmesysteme und durch diverse Geräte zur Bestimmung von Position und Lage die An-Bord-Verarbeitung von Bilddaten möglich ist. Die Bild- und Lagedaten sind bereits während des Fluges verfügbar, so daß eine Datenverarbeitung direkt am Sensor durchgeführt werden kann.
Das hier vorgestellte Verarbeitungskonzept ist für CCD-Zeilen-Scanner ausgelegt und ermöglich die sequentielle Verarbeitung ihrer Bilddaten.

1. INTRODUCTION

Spaceborne or airborne imaging sensors are sources of enormous data amounts. Generally all these data are transmitted from an aircraft or from a satellite to any receiver station on the earth. But actually the user is just interested in some particular data products. Sometimes only a few parameters and information are relevant (fire detection). So actually it were the best to process all data close to the sensor (onboard) and transmit the data products. One of the essential demands towards onboard algorithms is the ability to work online. Online in this context means that the prime flow of data is one way through different processing units. It also means that there is no interaction between the operator and the processing chain. If an algorithm works online one can think about making it fast and robust enough to use it onboard.
Besides this onboard problem there is another point pleading for an online processing. A lot of data sets have to wait too long for their processing, because of the enormous man and machine power needed. So an automatic processing of the raw data up to any product is desired.
The concept introduced here is developed for data of the CCD line scanner WAAC (Sandau, Eckardt 1996). It allows the processing of its image data up to digital terrain models (DTM) and could be a startpoint for an onboard processing method.

Usually images of CCD line scanners can not be handled like aerial photos. The main differences are:

- The geometry of images of line scanners is not fixed, because the second dimension of the image (flight direction) is influenced by the movements of the sensor.
- Hence a set of parameters of the interior and exterior orientation is needed for each CCD line at exposure times. These parameters have to be measured (GPS, Inertial Navigation System - INS, laser gyros) and have to fulfil the demands for accuracy defined by the ground resolution.
- Images taken with different viewing directions can not be oriented relatively to each other.

Consequently important parts of the processing algorithms for CCD line scanner data can not be the same as the algorithms for aerial photos or CCD matrix images. A characteristic example is the matching procedure. The flight motions cause image disturbances. Because of this effect image correlation can not be done. After an image correction, matching works well. But a determination of any object coordinates from these images is impossible, because the relation between a pixel and its orientation parameters disappears. The following chapter shows one possibility how to process such kind of data and to overcome the problems mentioned.

2. ONLINE PROCESSING CHAIN

The input data are the raw images (disturbed) and the attitude data from GPS, INS and from the gyros. Output should be any coregistration between images of two different CCD lines or a DTM. The data processing chain looks like the following:

- Image Correction
- Search for Startpoints for Matching
- Matching
- Backtransformation of the Conjugate Points
- 3D-Reconstruction
- Interpolation

These parts of the processing chain will now be explained.

2.1 Image correction

Figure 1 shows an example how images retrieved from an airborne CCD line scanner can be disturbed by the flight motions of the aircraft. It is an extreme example, of course, but such situations can not be excluded. In this image it seems to be impossible to do any image processing at all, e.g. matching. Therefore the images have to be corrected first. Different methods were tested to overcome this problem. One method was to describe the disturbances with an affine transform. It worked quite well partially but not for all lines. So another approach was used.

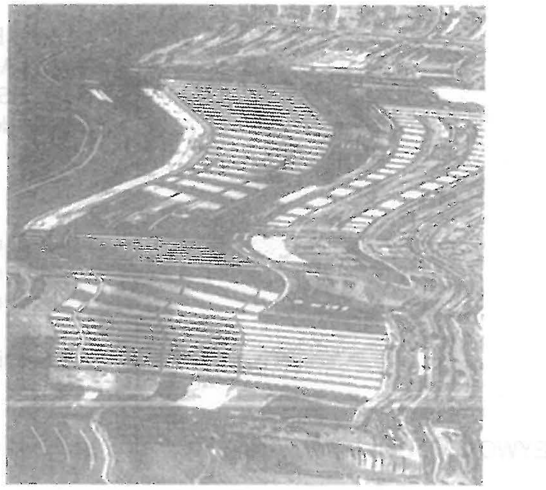

Figure 1: Uncorrected image

All pixels of the raw image were projected onto a reference plane. Figure 2 illustrates the situation.

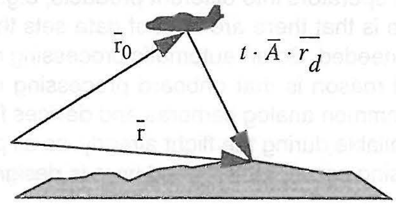

Figure 2: Position of the aircraft and of the object point

For each object point an equation exists like

$$\bar{r} = \bar{r}_0 + t \cdot \bar{A} \cdot \bar{r}_d$$

with

$\bar{r}$ - Position of the object point with $\bar{r} = (x, y, z)$
$\bar{r}_0$ - Position of the aircraft with $\bar{r}_0 = (x_0, y_0, z_0)$
t - Parameter
$\bar{A}$ - Rotation matrix, elements: $a_{11} \ldots a_{33}$
$\bar{r}_d$ - Viewing direction of a pixel

For a reference height at $z = H$ the position of the projected point is given by the colinearity equations

$$x = x_0 + (H - z_0) \cdot \frac{a_{11} \cdot x_d + a_{12} \cdot y_d + a_{13} \cdot z_d}{a_{31} \cdot x_d + a_{32} \cdot y_d + a_{33} \cdot z_d}$$

$$y = y_0 + (H - z_0) \cdot \frac{a_{21} \cdot x_d + a_{22} \cdot y_d + a_{23} \cdot z_d}{a_{31} \cdot x_d + a_{32} \cdot y_d + a_{33} \cdot z_d}$$

with

a_{ij} - Elements of the rotation matrix
Index d - Element of the viewing direction vector
Index 0 - Element of the position vector

In Figure 3 the result of such a correction is shown. In these corrected images the matching procedure works better than in the uncorrected images. It should be noted that it is not possible to determine any object coordinates in these images with the standard algorithms, because the relation between the image data and the attitude data is lost after the correction. For each pixel in the uncorrected

raw images there is an appropriate line number and consequently all orientation parameters are known (as far as they were measured). After the correction this simple relation between the pixel and its orientation parameters is destroyed.
The received images are not equal to images taken by a matrix camera. Errors could only be avoided, if all pixels would be projected on their real height, which means that the DTM for this region has to be known already.

Figure 3: Corrected image

2.2 Search for Startpoints for Matching

The next step is finding startpoints for the matching procedure in the corrected images. Image pyramids are created in order to minimize the search area. In the topmost level of the first image the most interesting points are detected with the help of an interest operator (Förstner 1986, Moravec 1977). In the second image the conjugate points are determined by looking for the biggest crosscorrelation coefficient. Than the startpoints will be projected towards the next levels up to the original corrected image. Wrong pairs of startpoints can be often detected quite easy. In Figure 4 parts of images taken near the Etna (Campaign in July 1996) by two different CCD lines (backward and nadir) are shown. Four startpoints were detected.

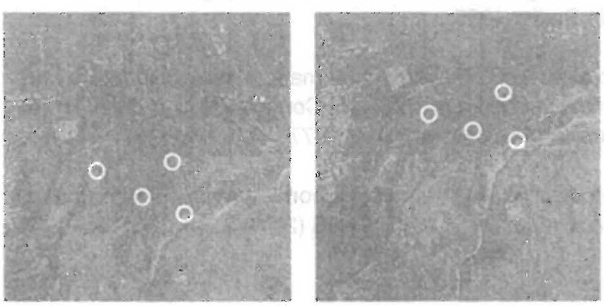

Figure 4: Detected startpoints in a backward and a nadir image

2.3 Matching

By beginning with these startpoints in the corrected images a region growing algorithm tries to find conjugate points. At first the neighbours of the startpoints will be checked. If they fulfil the match criterion the algorithm tests their neighbours in turn. The match criterion used here is the maximum of the crosscorrelation coefficient in a search area in the second images. An additional advantage of using corrected images is that the search area in the second image is much smaller than the one in the uncorrected images. In Figure 5 one can see how the matching algorithm did work. All conjugate points are marked as white dots. The large area without conjugate points in the middle of the region was caused by wood. Matching algorithms using the correlation between two images have generally difficulties with self-similar regions.

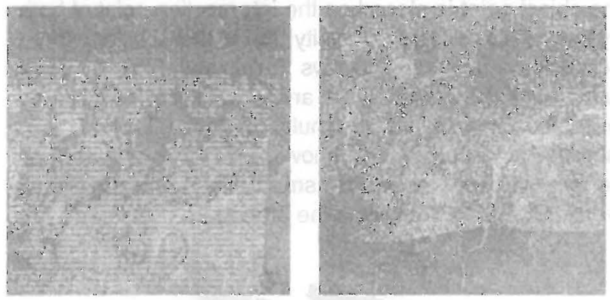

Figure 5: Result of Matching

2.4 Backtransformation of the Conjugate Points

As mentioned above an accurate determination of object points in the corrected images just with the ideal parameters of the orientation is not possible. In order to avoid these errors the origin of each pixel in the corrected images has to be known in order to use the corresponding attitude data set. So the question is, where a pixel in a corrected image came from. The first possibility is to remember the origin of each corrected pixel in the uncorrected image. But since two integers for each pixel have to be saved, large additional data have to be stored. So this method is applicable for small images or image parts only. The second possibility is the calculation of the original position. Figure 6 illustrates the problem.

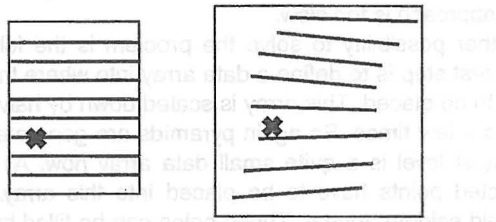

Figure 6: Position of the lines in an uncorrected and in a corrected image

The first step for this backtransformation is finding the original CCD line where the corrected pixel came from. So just the coordinates of the start- and the endpoints of each pro-

jected CCD line in the corrected image have to be stored. The pixel in the corrected image belongs to the line with the smallest distance between the projected line and the point itself. If the original line is found then a data set for the parameters of the exterior orientation can be derived.
After having found the corresponding CCD line it is possible to determine the original pixel number by the known colinearity equations (see equations for the correction of the images). Now the coordinates of the matched points in the raw images and the parameters of the interior orientation are known.

2.5 3D-Reconstruction

For all these conjugate points it is possible to determine the three-dimensional object coordinates in the following simple way. For each pixel the position and the viewing direction are known. So-called pixel rays can be defined. The object point is placed on the intersection point of both rays in the ideal case, in reality this is the position where the distance between the rays is minimal. Now for each pair of conjugate points there are three object coordinates available. The use of a simulation tool (Reulke 1995) showed that with the exact knowledge of the attitude data the reconstruction errors are smaller than one pixel in all directions. Figure 7 explains the procedure.

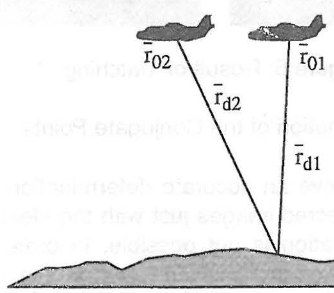

Figure 7: Reconstruction of an object point

2.6 Interpolation

In order to retrieve a digital elevation model, the irregular grid must be transformed into a regular one. Besides, holes should be closed and blunders should be removed. Usually a triangulation will be done, this means that triangles connect the original points. The values for the regular grid are determined by these triangles. For large data sets this approach is too slow.
Another possibility to solve the problem is the following: The first step is to define a data array into where the DTM has to be placed. This array is scaled down by halving the sides a few times. So again pyramids are generated. The topmost level is a quite small data array now. All reconstructed points have to be placed into this array. Holes should seldom appear. These holes can be filled by using bilinear interpolation. The next step is putting the values of this data array into the next pyramid level. Again all reconstructed points have to be placed into this array and bilinear interpolation closes the holes. This procedure will be repeated until the desired resolution of the DTM is reached. Any kind of filtering, like median and smoothing, can be added. Such a DTM can be seen in figure 8.

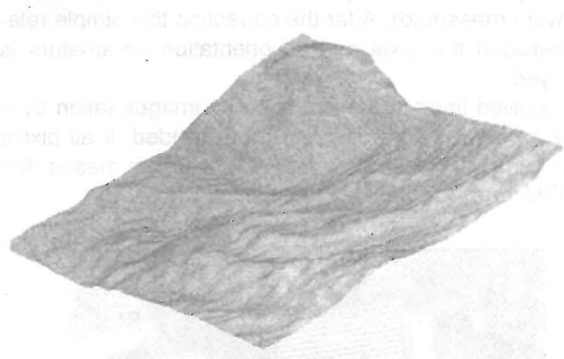

Figure 8: DTM

3. RESULTS

An online processing chain for stereo data was introduced. It allows an automatic processing of CCD line scanner data. For processing of large images (5000 times 20000 pixels) these images have to be split. The algorithm itself can be used for onboard processing.
Because of its modular structure it can be adapted to other data sets easily. Other algorithms can be included as well.

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