THE OPTIMIZATION OF THE STEREO ANGLE OF CCD-LINE-SCANNERS

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ABSTRACT

CCD-line-scanners are a real alternative to usually used aerial cameras. The principle of this type of cameras is the application of some CCD-lines with different viewing directions (stereo angle). For the determination of the optimal value of this camera parameter there is no reliable investigation or simple mathematical approach up to now. The paper presents the results of the optimization of the stereo angle of CCD-line-scanners using a simulation tool.
The optimization was done the following way: With the help of a digital terrain model (DTM) a couple of images was generated. A match algorithm was used to find conjugated points in these pictures. This information and the knowledge about the position of the simulated flight allows a reconstruction of the DTM. The comparison of both the original and the reconstructed DTM gives error criterions. With changing of certain parameters of the simulated camera the most suitable configuration for a special scientific task can be found.
The result of the investigations was that a stereo angle between 15 and 20 degrees gives the best accuracy in generating of DTM's for all simulated cases.

KURZFASSUNG

CCD-Zeilen-Scanner stellen eine reale Alternative zu den gewöhnlich genutzten Luftbildkameras dar. Das Grundprinzip bei diesen Kameras besteht in der Nutzung von mehreren CCD-Zeilen mit unterschiedlichen Blickrichtungen (Stereowinkel). Zur Bestimmung eines optimalen Wertes dieses Kameraparamters gibt es derzeit noch keine zuverlässigen Untersuchungen oder einfachen mathematischen Ansätze. Dieser Beitrag stellt die unter Nutzung eines Simulationspaketes erzielten Ergebnisse der Optimierung des Stereowinkels von CCD-Zeilen-Scannern vor.
Die Optimierung wurde anhand folgenden Zyklus durchgeführt: Mit Hilfe eines vorliegenden digitalen Geländemodells (DTM) wurden zwei Bilder eines Geländeabschnittes erzeugt. Ein Match-Algorithmus wurde benutzt, um äquivalente Punkte in diesem Bildpaar zu finden. Mit diesen Informationen und den Lagedaten des simulierten Fluges kann wiederum ein DTM erstellt werden. Über den Vergleich des Ausgangsmodells mit dem rekonstruierten sind Fehlerkriterien definierbar. Durch die Veränderung bestimmter Kameraparameter lassen sich die für eine spezielle wissenschaftliche Aufgabenstellung beste Sensorkonfiguration ermitteln.
Das Resultat der Untersuchungen ist, daß ein Stereowinkel zwischen 15 und 20 Grad für alle simulierten Anwendungsfälle bestmögliche Ergebnisse bei der DTM-Erstellung gewährleistet.

1. INTRODUCTION

CCD-line-scanners are real alternative to usually used aerial cameras. To get any information about the elevation of a point in an observed terrain at least two projections of it shot with different viewing directions are necessary. One possibility for realizing it is to use a scanner with at least two CCD-lines (two lines just for ideal flight paths), which generate images continuously. There are a few cameras utilizing this principle. One example is WAOSS (Wide Angle Optoelectronic Scanner). This camera is a technical contribution of the German Aerospace Research Establishment (DLR) to the MARS 94/96 mission (WAOSS, 1991a, 1991b). To get more stable results in stereo-processing WAOSS uses three CCD-lines. The first one looks forward, the second one nadir and the last one backward. So in just one overflight all information needed for a 3D-processing are available (Fig. 1).

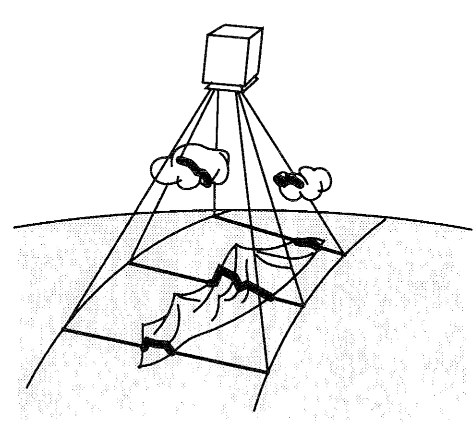

Fig. 1 CCD-line-scanner

The stereo angle is an important parameter for the derivation of digital terrain models (DTM) from remotely sensed image data. It characterizes the different viewing angles (Fig. 2).

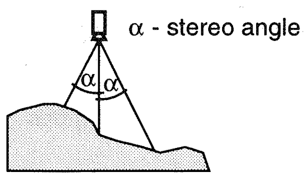

Fig. 2 Stereo angle

As reliable experimental investigations are either too expensive or simply impossible, the value for this parameter mainly is only estimated. Our investigations indicate that the use of a simulation technique may be the best way to get a satisfying result.
Such a simulator has been developed in the Institute of Space Sensor Technology (Reulke, N., 1995; Reulke, R., Reulke, N., Jahn, H., 1994). It allows the generation of image data of a very complex scene, encompassing the radiating or reflecting surface of a planet, the propagation of the radiation through the atmosphere and through the optical components, the conversion of the optical into an electronic signal, and the signal processing.
The simulator consists of three parts. The first one simulates the geometric properties (like orbit, planet, position of the sun), the second one includes the radiometric conditions, and the last module takes care of the analogous electronic part of a camera (Fig. 3).

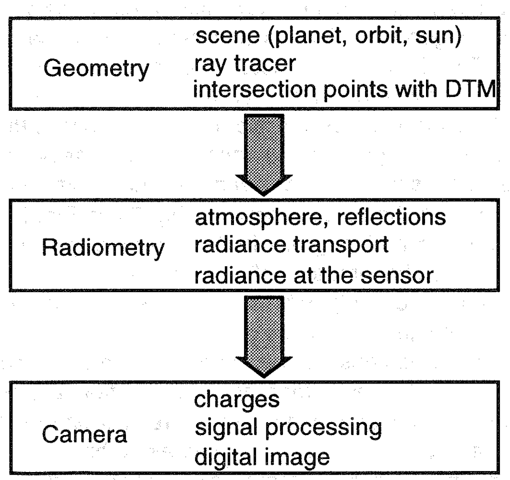

Fig. 3 Simulation tool

Algorithms for the data processing can be added. The application of this simulator gives the opportunity to optimize camera parameters and to define optimal detecting conditions.
The basic idea was that an optimal stereo angle strongly depends on the structure of the observed terrain. With the following procedure our simulation technique makes possible such an optimization:
With the help of the simulator image data have been generated, basing on a digital terrain model obtained from previous Mars missions. A DTM of the Mars was chosen, because WAOSS is a Mars-camera. Besides there should be no limitation regarding other landscapes, the DTM was changed by different exaggeration factors for our investigations.
These images were matched in order to find conjugated points. A match algorithm of the Technical University of Munich was used (Heipke, C., 1994), which evaluates the local image point correlation. The first step is choosing a number of start points. Outgoing from these start points the matcher tries to find conjugated points. The result of this procedure is a file containing the coordinates of the conjugated points in the image plane.
The knowledge of the location of the conjugated points, of the simulated flight position and of the viewing direction of every detector element allows the generation of a new terrain model. This part of the processing cycle yields a more or less dense net of elevation samples. Elevation values between these samples are available after an interpolation procedure.
By comparing both DTM's a error criterion can be defined. The analysis of the spatial and temporal dependencies of this criterion on any parameter of the environment and/or the camera then enables the adaptation of a camera parameter to the relevant scientific task (Fig. 4). So an optimal parameter can be found.

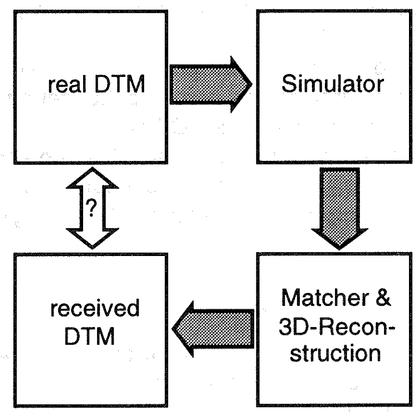

Fig. 4 Scheme of processing

2. Optimization of the Stereo Angle

Already from the beginning it was predictable that a few processes should influence the optimal stereo angle. The most important ones will be outlined.
The relative shift of a certain point in two images is the decisive measure for the determination of its elevation. Since there is an absolute error due to the spatial discretization by the optoelectronic system, the relative error decreases with an increasing stereo angle (Fig. 5). Accordingly, the whole DTM must become more accurate.

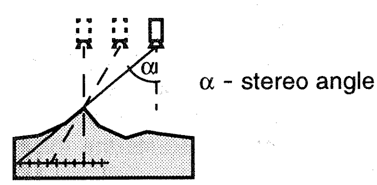

Fig. 5 Relative shift of conjugated points in dependence on different stereo angles

The opposing effects are: The larger the stereo angle, the bigger the perspective distortions. It means that different CCD-lines get different impressions of one area (Fig. 6).

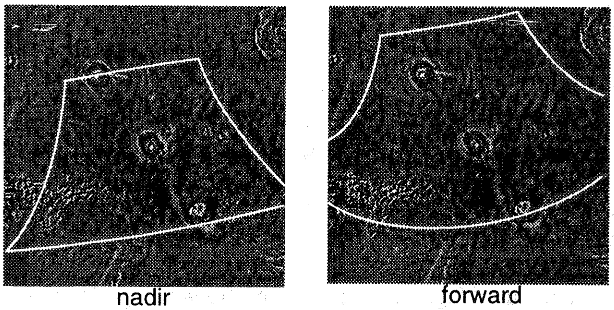

Fig. 6 Track of the border pixels of two different lines

So it is getting more difficult for the match algorithm to identify points correctly. The probability of wrong match results increases. This is especially important for highly elliptical satellite orbits.
Shading caused by the optical components of the system (cos^4-law) influences the signal-to-noise ratio of the data. This ratio is not only determined by the field of view, but by the stereo angle as well. Consequently the bigger the stereo angle, the smaller the signal-to-noise ratio. And again it becomes more difficult for the match program, to find conjugated points.
Besides there is still another point. The larger the stereo angle, the more it becomes probable that certain areas on the surface are invisible for a CCD-line.
The last three effects plead for a small stereo angle.
These counteracting processes are responsible for the formation and definition of an "optimal" stereo angle we want to find.

3. Investigations

The value of this optimal value of the stereo angle was determined in dependence on the following parameters (Börner, A., 1995):
- elevation dynamic of the observed terrain
- ground resolution of the camera.

3.1. Influence of elevation dynamic

Elevation dynamic in this contents means the standard deviation of the original elevations given as a grid of samples. The distance of these samples should be equivalent to the ground resolution of the camera.
In order to have comparable conditions one area of the Mars was selected. The existing terrain model was modified in the following way:
The DTM was compressed by factor 5 once and exaggerated by factors 3,4 and 5. The simulated ground resolution is about 1 km and resulted from 256 pixels per line, a field of view of 80 degrees and a flight height of 150 km. This value corresponds to the resolution of the original DTM of Mars (U.S. Geological Survey, 1992).
For the evaluation of the results the following criterions were selected:
- accuracy of single reconstructed points
- number of matched points
- accuracy of the whole reconstructed DTM.

A measure for both accuracies is the standard deviation of the elevation errors. The results of the investigation are shown in Fig. 7 to Fig. 9. In Fig. 7 the standard deviation of the elevation errors of all matched points is drawn in dependence on the exaggeration factor and the stereo angle. It could be established that up to a value of about 15 degrees for the stereo angle the determination of the elevation of single points is getting more accurate. After that there is no improvement of the results. So it makes no sense to make the stereo angle greater than this value. A stereo angle smaller than 10 degrees yields too large errors.
The second curve shows the number of matched points in dependence on the stereo angle and the exaggeration factor. The more the original DTM was exaggerated the less the number of conjugated points could be found. Also the number of matched points decreases with an increasing stereo angle. In the previous section was tried to explain the reasons for this effect. The exaggeration factor causes an increase of the local elevation dynamic. Since the used match algorithm evaluates the local image correlation, it is clear that a strong local elevation dynamic causes a rapid change of the local image correlation even for small changes of the viewing direction. An extreme example for such a kind of areas are urban terrains. The nadir line just sees the roofs and no walls, the other lines have a totally different impression.
Even for flat areas the number of conjugated points decreases drastically for stereo angles greater than 40 degrees.
Fig. 9 is the result of the two previous curves. It shows the standard deviation of elevation errors of the whole DTM, i.e. the interpolated points were taken into consideration. For all exaggeration factors a minimum of these curves exists. The bigger the factor the more the minimum becomes expressed. For flat areas the stereo angle doesn't play any important role. But for terrains with a big local elevation dynamic the range of permissible stereo angles gets smaller. The parts of the curves can be explained with the results shown in Fig. 7 and Fig. 8. Up to a value of about 15 degrees for the stereo angle the standard deviation becomes smaller. After that the influence of the interpolation algorithms increases, because the number of conjugated points decreases.
The large deviations of the measured values from the curves in the plots even for great exaggeration factors indicate an essential dependence of the results on the choice of the starting points of the matching algorithm.
To sum up, there are permissible ranges of the stereo angle in dependence on the elevation dynamic of the observed area. But the application of an stereo angle between 15 and 20 degrees enables a sufficient accuracy in determining single point elevations as well as a sufficient number of conjugated points in two images.

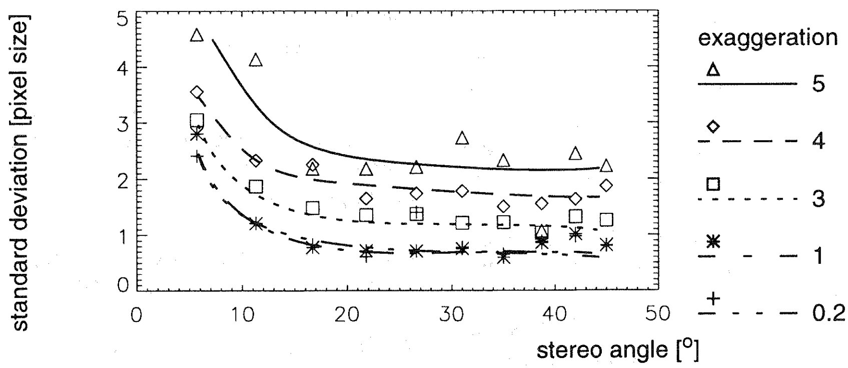

Fig. 7 Standard deviation of elevation errors of single points in dependence on the exaggeration factor

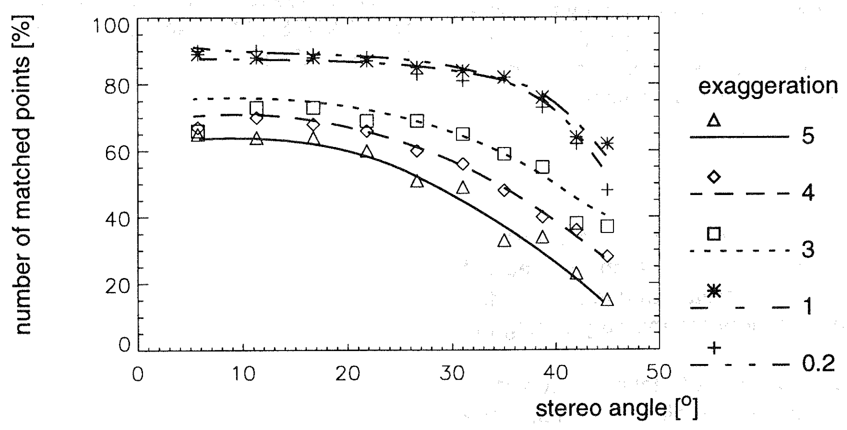

Fig. 8 Number of matched points in dependence on the exaggeration factor

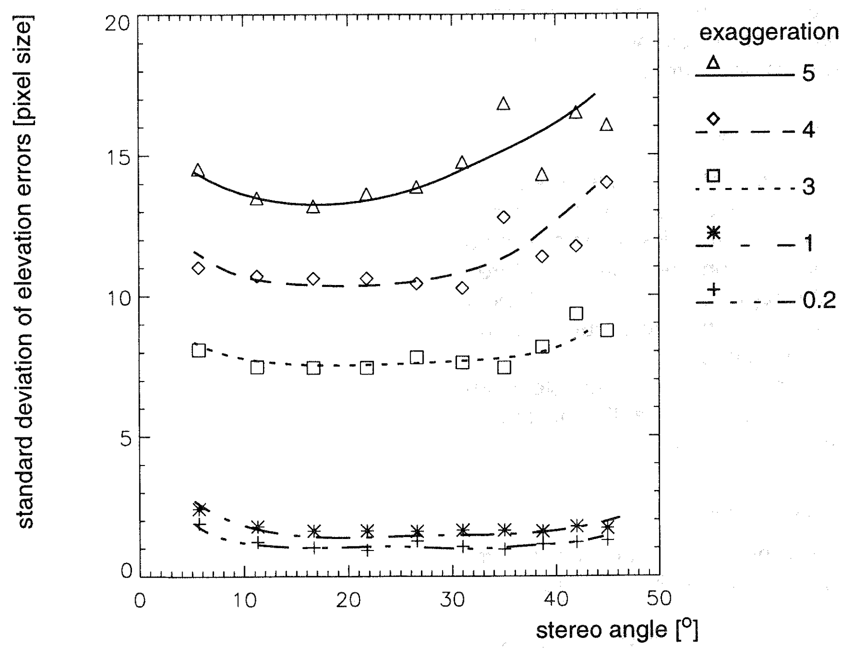

Fig. 9 Standard deviation of height errors of the whole DTM in dependence on the exaggeration factor

3.2. Influence of ground resolution

A few test series with different ground resolutions of the optoelectronic system were carried out. There are two ways to realize it. The first one is to change the flight height, the second one is a change of the field of view with a constant number of pixels per line. Both ways yield the same results.
It could be established that the influence of the camera's ground resolution is not as drastic as the influence of the area's elevation dynamic.
Consequently it would be better to reduce the data rate of a camera by using macro pixels and not by using a greater compression factor. The blocking effects caused by certain compression algorithms make it harder for the match algorithm to find conjugated points, so the number of matched points decreases. The elevation error caused by the lower number of matched points could be much greater than the error caused by a smaller ground resolution of a camera.
In general the results of the previous chapter could be established.

3.3. Other aspects

Another point to plead for a small stereo angle is that the stereo processing just can be started, when all lines got information about the same area. Consequently the greater the stereo angle the bigger the memory storing the image and position data.
In contrast to the simulation we have to take into consideration a bi-directional reflectance in reality. The smaller the stereo angle the smaller the differences of images caused by this effect.
Maybe a more intelligent and more expensive match algorithm is able to match a sufficient number of points even if the stereo angle is large. But actually there is no need for a great stereo angle, because the accuracy to determine a single point's elevation will not be improved.

4. Conclusion

The main results are: An optimal stereo angle exists and should be between 10 and 40 degrees. The permissible range depends on the elevation dynamics of the observed surface and on the camera's ground resolution. A stereo angle between 15 and 20 degrees leads to a sufficient number of matching points and to a good accuracy of the elevation values under all conditions.
These results underline the importance of a suitable simulation technique for the design and optimization of camera parameters and observation conditions.

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