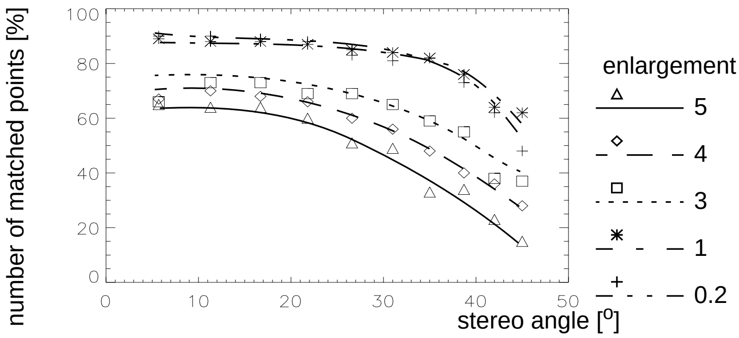

Fig. 5 Number of matched points in dependence on the enlargement factor

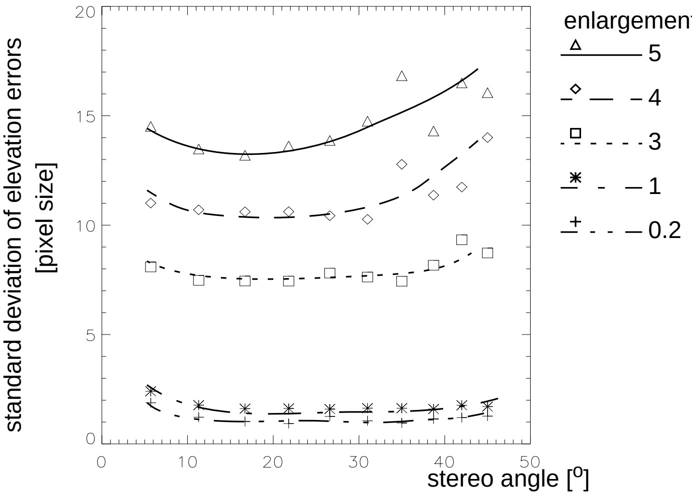

Fig. 6 Standard deviation of height errors of the whole DTM in dependence on the enlargement factor

area‘s elevation dynamics.

4. CONCLUSIONS

This paper describes an optimization approach based on an end-to-end simulation tool. The simulation includes a scientific parameter of the scene, the sensor in its environment and evaluation algorithms. This method is part of a comprehensive description of the measurement process.

The quality of the simulation and optimization depends strongly on the models and algorithms used. Tests of the simulation results are therefore necessary and must be performed

- with the original instrument for Earth applications [9] and
- with data from earlier missions.

The described simulator is not limited to optimization tasks. Other applications areas using this approach are

- investigations of the sensitivity of different data products to position and calibration errors,
- test of retrieval algorithms and
- mission support.

With the simulator a powerful tool was created for different sensor development applications.

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The stereo angle or the distance between the forward/ backward line to the nadir line, is an important parameter for the accuracy of the derivation of digital terrain models (DTM) from remotely sensed image data. It is obvious, that the stereo angle depends on the structure of the investigated surface. Even though different CCD-stereo scanner were used on aircraft or spacecraft no calculation for an optimal stereo angle is known.

The procedure described below makes an optimization possible.

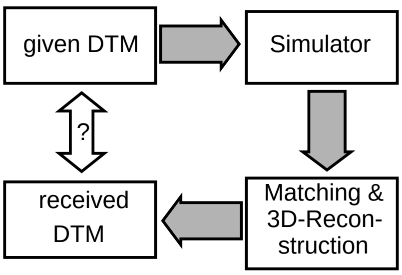

Fig. 3 Scheme of optimization procedure

With the help of the simulator, image data have been generated, based on a digital terrain model. A DTM of Mars ([6]) was chosen. There should be no limitation regarding other landscapes because the DTM was changed by different enlargement factors for our investigations.

These images were matched in order to find conjugated points. A match program of the Technical University of Munich was used ([3]), which evaluates the local image point correlation.

The knowledge of the location of the conjugated points and of the simulated flight position allows the evaluation of the terrain model. This part of the processing cycle yields a more or less dense net of elevation samples. Elevation values between these samples will be available after an interpolation procedure.

By comparing both DTMs, the original and the derived, a error criterion can be derived. The analysis of this error enables the adaptation of a camera parameter to the relevant scientific task (Fig. 3). So an optimal parameter set can be found.

The determination of the stereo angle is a typical optimization problem, because different effects work in opposite directions.

The absolute shift of the same object 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. 4).

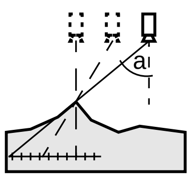

Fig. 4 Relative shift of conjugated points in dependence on different stereo angles

The opposing effects are that the larger the stereo angle, the bigger the perspective distortions and parts of the terrain are situated in a view shadow. So the number of matched points and their accuracy decrease with increasing stereo angle.

An additional effect - the fading of the optics at the edges caused by the $\cos^4$-law influences the signal-to-noise ratio of the data. This ratio is not only determined by the field of view, but also by the stereo angle. Consequently bigger stereo angle results in a smaller signal-to-noise ratio and this influences the number and accuracy of matched points.

The optimal value of the stereo angle was determined with respect to the following parameters ([2]):

- elevation dynamics of the observed terrain
- ground resolution of the camera.

Elevation dynamics means the standard deviation of the elevations, as given in a grid of samples.

In order to have comparable conditions one area of Mars was selected. The existing terrain model was compressed by a factor 5 and enlarged by factors 3,4 and 5. The simulated ground resolution is about 1 km and this is derived 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 ([6]).

Following error criteria were selected:

- accuracy of single reconstructed points
- number of matched points
- accuracy of the whole reconstructed DTM.

The results of the investigation are shown in Fig. 5 and Fig. 6. For the standard deviation of the elevation errors of all matched points, it was found 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 errors which are too large.

The curve in Fig. 5 shows the number of matched points in relation to the stereo angle and the enlargement factor. The more the original DTM was enlarged the fewer the number of conjugated points could be found. The number of matched points decreases with an increasing stereo angle. The accuracy of the matched points does not change.

Fig. 6 shows the result for the error of the DTM-retrieval. The increasing accuracy for small stereo angles results from increasing of the accuracy of the matched points. The decreasing accuracy of the DTM with further increasing of the stereo angle depends only on the decreasing number of matched points.

To sum up, there are permissible ranges of the stereo angle with respect of the elevation dynamics of the observed area. But the application of a stereo angle between 15 and 20 degrees provides a sufficient accuracy in determining single point elevations as well as a sufficient number of conjugated points in two images.

A few tests with different ground resolutions of the optoelectronic system were carried out.

It could be identified that the influence of the camera‘s ground resolution is not as drastic as the influence of the an error criterion becomes possible.

The simulation system consists of mathematical and physical models to simulate the transfer of electro-magnetic radiation from the source of the emission to the sensor.

Examples for optimization with this tool are published in [2], [4] and [8].

Different applications of this simulation approach have been considered: first of all, the preparation of the Wide Angle Optoelectronic Stereo Scanner (WAOSS) for the Mars'96 mission ([7]). A crucial feature of this camera is the in-track stereo capability which is realized through a three-line CCD arrangement. This camera is used for the investigation of large-scale phenomena. For the Mars'96 mission a highly elliptical orbit was selected. The most important consequences of the chosen orbit are variable clock- and integration times, in order to receive comparable images of the surface and nearly square pixels. The choice of the orbit and hardware demands lead to a variation of all essential quantities such as scale, ground resolution, and signal-to-noise ratio, both across-track and in flight direction with consequences for all data processing and evaluating algorithms.

After the description of the simulator the calculation of an optimal stereo angle is described. The stereo angle is an important parameter for the derivation of digital terrain models from CCD-line-images.

2. SIMULATOR

A simulator allows the generation of image data of a very complex scene. This encloses the radiating or reflecting surface of a planet, the propagation of the radiation through the atmosphere and the optical components, the conversion of the optical into an electronic signal, and the signal processing.

The key part of this simulation system is a ray tracer interacting with a digital terrain model around an ellipsoid. The simulator consists of three parts (see Fig. 1):

1. Generation of a reflection image.

   This is accomplished using a ray-tracing procedure in a digital terrain model (DTM).

   The reflection model is Lambertian, bidirectional models can be integrated.

   The sensor geometry can be a CCD line or a matrix camera.

2. Calculation of the radiation intensity in front of the CCD.

   The transmission and scattering in the atmosphere, the reflection properties of the surface are used.

   Spectral filters and angular dependencies of the optics have been considered.

3. Modelling of the camera electronics.

   Statistical noise in particular is added to each pixel.

However the real signal generation process is more complex. There are multiple interactions between atmosphere and surface for example, so that the geometric part and the radiometric part are not independent on each other as described in Fig. 1. But the independence of each part makes the simulator efficient, sequential and modular.

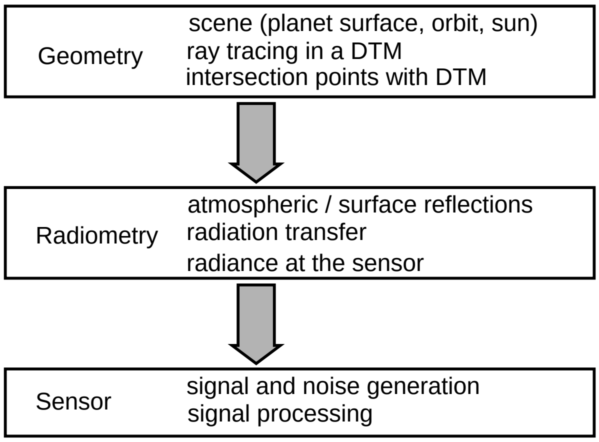

Fig. 1 Simulation tool

Algorithms for data processing can be added.

This approach has been developed primarily for the simulation of image data. Due to modularity other applications can be simulated with the same approach. Only the complexity of the algorithms and the result of each simulation step are different.

For a camera application the result of the geometric part is the surface normal of the intersection point for the determination of the reflected or emitted signal.

An application of the simulation approach for a spectral analysing measurement system has been described in [8]. The aim of this simulation tool is the generation of signals in the vicinity of Saturn. The result of the geometric part are the parameters for the spectral line generation like drift velocity, illumination condition and the part of the target within the field of view.

3. OPTIMIZATION OF THE STEREO ANGLE OF A CCD-LINE SCANNER

To get the elevation of a point in an observed terrain at least two images with different viewing directions are necessary. The stereo principle from a CCD-line scanner is depicted in Fig. 2. In this example there are three CCD-lines in the focal plane (e.g. WAOSS). The first one looks forward, the second one to the nadir and the last one backwards. So in just one overflight, together with the flight path information, all information needed for a 3D-processing is available.

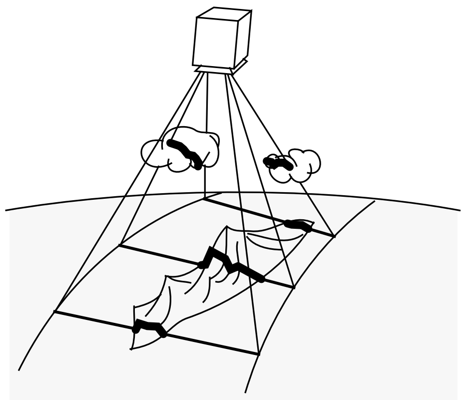

Fig. 2 CCD-line-scanner

OPTIMIZATION OF SPACEBORNE IMAGING SENSORS WITH AN END TO END SIMULATION SYSTEM

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Abstract

To optimize a sensor (and a mission), the existing knowledge about the scientific problem and about the available technology should be used. That is the objective of the optimization concept used here.

The optimization concept is based on an error function which compares assumed values with the estimated values of the parameters provided by the experiment. The error on the consideration is a function of some instrument (and mission) parameters which can be optimally chosen by minimizing the error function taking into account the technological (and cost) limitations.

For this approach a numerical simulation tool has been developed that allows computer experiments with specific sensor configurations for design and optimization of optoelectronic sensors for specific (well known) applications.

Such a concept is important for the development of dedicated sensors for well defined remote sensing tasks to obtain the optimal solution of the problem.

1. INTRODUCTION

Spaceborne projects are characterized by well known scientific objectives, restriction of the measurements (orbit, observation conditions, data transmission) and are developments at the technological limitations of today.

Typically, the optimization of spaceborne sensors for a special task is accomplished by maximizing characteristic numbers of the optoelectronic system, e.g. ground resolution and signal to noise ratio. But the physics of the image recording process is more complex and cannot be described with these simple parameters. And, because of the complexity of remote sensing problems, in most cases there is no simple relation between these quantities and the optimal solution of the scientific questions.

Frequently the ground resolution is defined by the distance between two pixel centres, projected on a planets surface. A better approach considers effects resulting for example, from the atmosphere, optics and sensor electronics, which reduce the geometric resolution. These blurring features can be described by the point spread function (PSF) or modulation transfer function (MTF) [1].

An analogue description must be applied for the noise. Noise determines another fundamental quantity for a system description - the signal to noise ratio (SNR) or the radiometric resolution of the system.

Noise, which is generated by the detector, the front-end-electronics and some external sources, is not a number but has a frequency dependency.

All system quantities depend on each other. For example a better geometric resolution can be reached with smaller pixels. This results in a smaller signal and a smaller SNR.

Longer integration time results in a better SNR but for moving objects or sensors there is in addition more blurring or worse geometric resolution.

The geometric resolution necessary for a special system depends on the scene as defined in the scientific objectives. A smooth or flat scene needs a coarse geometric resolution, which results in a cheaper system, smaller data rate and better data quality.

The determination of the necessary geometric resolution of the system can be calculated for example with the sampling theorem by relating the maximum possible space frequency from the scene with the Nyquist frequency of the imaging system [1].

This is a very common approach for optimizing a geometric resolution with physical properties of the scene and the imaging system.

But the definition of the resolution can be more complex, especially if the relation between the values of interest and the measuring system is only known implicit. An example is the determination of the height resolution from stereo images, as described below. Besides the geometric and the radiometric resolution the scene dynamics influence the derived result for a digital elevation model.

To apply an optimization scheme one needs data depending on the required parameters and a data evaluation procedure providing estimates of these parameters. One can use

- real data from a different camera from earlier missions,
- real data from the original camera on an Earth observing airborne platform,
- simulation of camera data for the future mission.

The future camera may have other spectral channels and recording principles compared to those from earlier missions. In airborne experiments often different regions are investigated which cannot be compared with those of the space mission, and there are additional problems with sensor platform positioning. Furthermore, ground truth is not always available. So in many cases the first two data sources are not representative for the new experiment.

Therefore a numerical simulation tool has been developed that allows computer experiments with specific sensor configurations for design and optimization of optoelectronic sensors for well known specific applications ([1],[4], [5]). The evaluation algorithm, adapted to the special problem, then uses these simulated data for estimating the input data. Now the comparison with the original data and the formulation of