COMBINED PROCESSING OF SPECTRAL AND STEREO DATA

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ABSTRACT

In the Institute of Space Sensor Technology and in the Institute of Optoelectronic of the DLR a multisensor concept is being developed. For this the 3-line CCD-stereo scanner WAAC, an infrared camera, and the hyperspectral system DAIS were flown several flight experiments. Mainly the combination of stereo and spectral resolving instruments has great synergy effects.
This paper describes the experimental setup and the data evaluation procedure. The first step is generating a geocoded digital elevation model (DEM) with a stereo image pair of WAAC. The second step is the coregistration of the spectral channels on this DEM.
The multisensor approach in acquisition and processing is capable of producing coregistered DEM's together with high spatial resolution stereo data and high spectral resolution data. Such data sets yield a high potential for a variety of interdisciplinary studies.

KURZFASSUNG

Im Institut für Weltraumsensorik und im Institut für Optoelektronik des DLR wird an einem Multisensorikkonzept gearbeitet. Hierfür wurden die 3-Zeilen-Stereo-Kamera WAAC, eine Infrarotkamera und das Hyperspektralsystem DAIS in mehreren Flugexperimenten eingesetzt. Besonders die Kombination von Stereo- und spektral auflösenden Instrumenten hat große Synergieeffekte.
Der Beitrag beschreibt den Aufbau und die Datenevaluierung des Experimentes. Der erste Schritt ist die Generierung eines geokodierten digitalen Geländemodells (DGM) mit Hilfe eines Stereobildpaares von WAAC. Der zweite Schritt ist die Koregistrierung der spektralen Kanäle auf dieses DGM.
Der beschriebene Multisensorikansatz in Aufnahme und Verarbeitung ist in der Lage geokodierte DGM's zusammen mit räumlich und radiometrisch hochauflösenden Daten zu erzeugen. Solche Datensätze stellen ein hohes Potential für eine Vielzahl von interdisziplinären Studien dar.

1 INTRODUCTION

The quantitative evaluation of multispectral airborne imagery has been an field of research for a number of years. These studies were often hampered by the dominating influence of the topography on the radiometry of the data.
Because of the differences in the geometry (pixel size and focal length) a hardware alignment between the different sensor pixel cannot be achieved. For sensors with different view geometry this problem needs a digital elevation model of the underlying surface.
The influence and correction of different topographic effects on satellite sensor signal, which are investigated by (Proy et al., 1989) and (Richter, 1996), require the availability of a DEM with the appropriate accuracy and spatial resolution. In many cases of airborne data acquisition the spatial resolution of the imagery is significantly higher than the one of an eventually available DEM. Even if such an accurate DEM is available, the geocoding of the airborne data especially in mountainous regions is a challenging task.
As a solution to these short comings, experiments were set up in which the small digital 3-line CCD-scanner WAAC (Wide Angle Airborne Camera) were flown together with a infrared system and the hyperspectral scanner DAIS 7915 (Digital Airborne Imaging Spectrometer) aboard the same aircraft. The main advantages of this configuration are the simultaneous acquisition of both data sets from the same platform and their instant availability in digital format.
From the WAAC stereo data a high resolution DEM is derived. This DEM, which is co-registered with the infrared and the hyperspectral data set, yields important topographic information such as terrain height, slope and aspect. This information allows e.g. a radiometric correction for each pixel with respect to atmosphere and topography.

2 EXPERIMENT AND SENSOR DESCRIPTION

2.1 DAIS-System Description

The Digital Airborne Imaging Spectrometer DAIS 7915 is a 79-channel high-resolution optical spectrometer, which collects information from the Earth's surface in the 0.4 - 12.3 µm wavelength region. Scanning from an aircraft, the system electronically processes all data into digital format consisting of 16 bit words, and records these digital data on a cartridge recorder (Chang et al., 1993, Strobl et al., 1997).
The DAIS scan mechanism is of Kennedy type, where a cubic polygon mirror scans the terrain below through the opened window hatch in the bottom of the aircraft. When operated aboard DLR's Dornier DO 228 aircraft the DAIS 7915 has a swath angle of 52°, which is covered with 512 pixels per scanline. The IFOV currently used is 3.3 mrad, giving a typical ground instantaneous field of view of 10 m and a pixel spacing of 5 m from a flight altitude of 3000 m above ground.
Table 1 presents an overview of the spectral characteristics as derived from the 1996 calibration measurements.

wavelength range	# of bands	band-width	detector
0.45 - 1.05 µm	32	15 - 30 nm	Si DC coupled
1.5 - 1.8 µm	8	45 nm	InSb AC coupled
1.9 - 2.45 µm	32	25 nm	InSb AC coupled
3.0 - 5.0 µm	1	2.0 µm	MCT AC coupled
8.7 - 12.3 µm	6	0.9 µm	MCT AC coupled

Table 1 Spectral band characteristics of the DAIS imaging spectrometer

The data used in this study were system-corrected using DLR's standard preprocessing software (Strobl et al., 1996) and laboratory calibrated to represent at-sensor radiance.

2.2 BIRD - System Description

BIRD the Bispectral Infrared Detection push broom scanner was designed for a small satellite mission. He is dedicated for the detection and analysis of high temperature events (HTE). For this purpose two infrared line scanners (3.4 - 4.2 µm and 8.5 - 9.3 µm) will be combined with the Wide Angle Stereo Scanner (WAOSS), which works in the visible spectral range. Adding to the infrared cameras a suitable CCD-line scanner for a preclassification with higher ground resolution, an improvement of the detection result in the infrared can be achieved.
Table 2 gives the main parameters of the sensor configuration.

Sensor parameter	MWIR	LWIR
wavelength	3.4 - 4.2 µm	8.5 - 9.3 µm
Focal length	46.39 mm	46.39 mm
Field of View (FOV)	60 mrad	60 mrad
f# number	2.0	2.0
element number	512x2 staggered	512x2 staggered
element size	30 x 30 µm	30 x 30 µm
ground pixel size (altitude 450 km)	290 m	290 m
swath width (altitude 450 km)	148 km	148 km
Quantization	16 Bit	16 Bit
Data rate	420 kbps	420 kbps

Table 2 Main parameters of BIRD IR-sensors

2.3 WAAC-System Description

In the DLR a miniaturized Wide-Angle Optoelectronic Stereo Scanner (WAOSS) was developed for the Russian Mars-96 mission. The test applications of this camera led to demands for a more flexible camera, more suitable for airborne imaging applications. So WAAC was developed based on this camera concept and reusing the WAOSS modules to a wide extent (Sandau et al., 1996).
The Wide-Angle Airborne Camera WAAC is a three-line stereo scanner working in the push-broom mode. According to the camera design, the image information will be generated within the image plane of one single objective by means of three CCD lines. With the knowledge of aircraft attitude data a stereo processing is possible.
For Earth-related airborne applications of a three-line stereo camera, the mass (4.5 kg), volume (L:285 mm x W:190 mm x H:202 mm), and power consumption (15 W) restrictions are of high importance. The camera control and imaging as well as gyro data collection is performed by only one PC.
After reducing the amount of data by means of special compression methods, the three image strips recorded will be stored on SCSI device.
The field of view of the camera is 80 degrees and the number of pixels is 5184 with an IFOV of 0.3 mrad. For a typical height of 3000 m the ground resolution is about 1 m. The spectral responsivity is different for nadir and backward / forward line. The nadir line is sensitive from 0.45 - 0.7 µm and the backward / forward line from 0.6 - 0.8 µm.

3 DATA-PROCESSING AND DEM-GENERATION

3.1 Preprocessing

WAAC yields radiometrically corrected images. The camera corrects within the recording process pixel response nonuniformity (PRNU), dark signal and intensity shades. Figure 1 shows examples of raw WAAC data from the nadir and backward line. As an example a flight over the Rigi region in Switzerland was used (N. Reulke, 1997).

3.2 Attitude determination

The use of WAAC on-board aircraft instead of satellites causes changes in measurement and evaluation procedures, particularly for the attitude instabilities of the aircraft (roll, yaw, pitch, ground speed and altitude variation), which are much more pronounced than those of the satellite. A stabilized platform was not used in the aircraft for reasons of simplicity, size and weight.
Besides the INS in the nose of the DO 228, a gyro block was mounted directly on the camera base plate. As the attitude angles given by the INS do not have the necessary accuracy, an optical fibre gyro system should be used instead of the installed INS.
During the data acquisition the following attitude data are recorded: The altitude (GPS and Inertial Navigation System INS of the aircraft), the ground speed (GPS and INS), the flight path angle (GPS), yaw, pitch and roll angle (INS), and the angular velocity (3 fibre optical gyros).
The evaluation procedure is explained in (Scheele et al., 1994).

3.3 Matching and DEM-generation

The first step is finding conjugated points in at least two different images using a matching algorithm. With the knowledge of their coordinates in the focal plane and the attitude of the sensor, so-called pixel rays can be defined. Because of the discretization errors caused by the finite resolution of the camera, the intersection point is the vector with the smallest distance between the pixel rays. This vector gives the 3D-coordinates of the reconstructed point.
If a sufficient number of terrain points could be calculated, a DEM can be retrieved by a two-dimensional interpolation algorithm (Börner, 1996). Figure 2 shows the result of the described procedure.

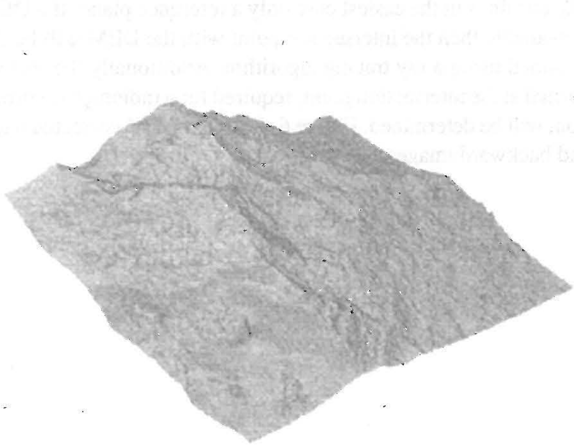

Figure 2 Retrieved DEM

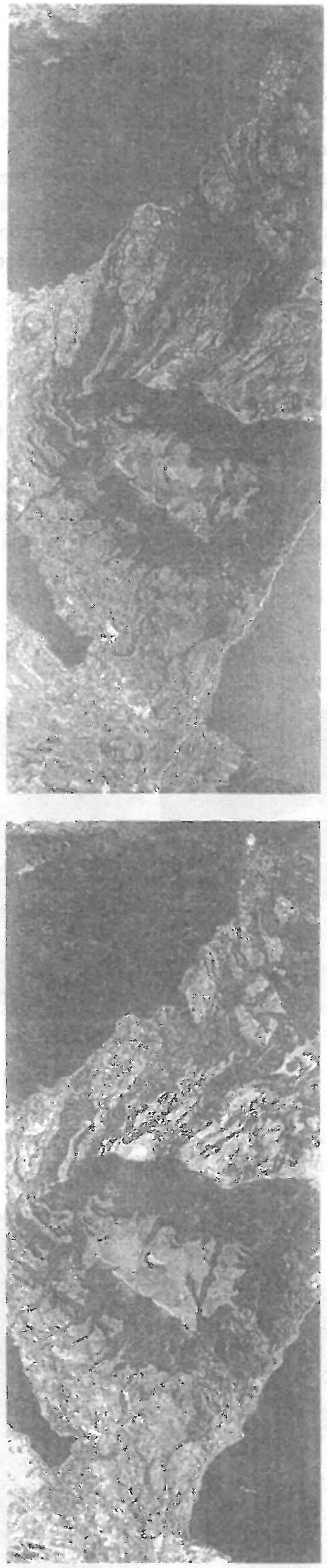

Figure 1 Original WAAC image strip from nadir (top) and backward (bottom) line

4 ATTITUDE CORRECTION AND COREGISTRATION

The coregistration procedure is a main task for the common interpretation of data recorded by different sensors. Mainly this is necessary for processing of high resolution spatial data and high resolution spectral data.
For airborne data the coregistration process is the first step for following procedures like attitude correction or later classification algorithms. Simultaneously the high resolution spatial data can be use for a more accurate correction of the spectral data.

4.1 Attitude Correction on a Plane

The evaluation approach for point size high temperature events requires a exact pixel alignment between different spectral channels. Because of the differences in the geometry (pixel size and focal length) a hardware alignment cannot be achieved. So at least a knowledge of the spatial geometrical relation between the IR and VIS sensor pixel is necessary. It can be measured in a calibration laboratory or in a first approach by comparison to a calibrated system.
The last procedure was tested on airborne platform with the nadir channel of WAAC and the LWIR channel. It was a flight over Oberpfaffenhofen near Munich. Figure 3 shows the same part of both original images.

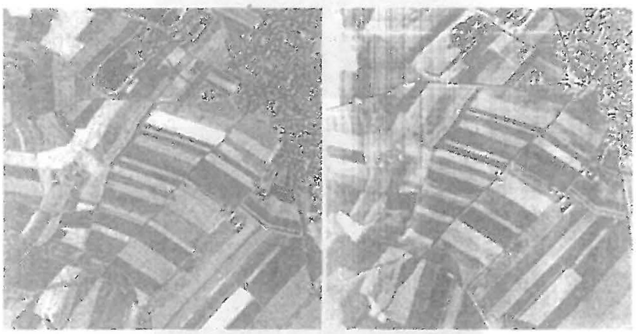

Figure 3 WAAC and LWIR - images

Because of the same viewing direction the IR and VIS data can be merged together with an affine transformation. For that purpose equivalent point in both images were chosen with an automatic algorithms and a manually one. Figure 4 shows a part of the whole image.

Figure 4 Merge of IR (upper left) with VIS image

From this image the differences in gray value distribution for the same object is evident. Together with worse image quality a simple correlation techniques doesn't work over the whole image. An alternative is a feature based approach.
The attitude correction of the IR-data is now possible. Because of the known correspondence to the VIS data the program described in (Börner, 1996) can be applied. Figure 5 shows the result. The correction accuracy can be visually proven on borders and roads.

Figure 5 Attitude correction of the IR-data

As a result, wave structures (e.g.roads and field borders) becomes straight.

4.2 Attitude Correction on a DEM

As a second approach for data over rugged terrain, the Rigi data will be corrected on a DEM. The first step of the correction is the calculation of the aircraft position at the recording time with the flight height, flight direction and flight velocity data. Another approach would be the use of the Global Positioning System (GPS). Using the geometric calibration information of the pixel, the viewing direction can be determined by the gyro information about roll, pitch and yaw angles described above.
After this procedure the aircraft position and the viewing direction of this pixel is known. With this information the intersection point of the viewing direction with the terrain will be calculated. The terrain is in the easiest case only a reference plane. If a DEM is available then the intersection point with the DEM will be determined using a ray tracing algorithm. Additionally the surface normal at the intersection point, required for a radiometric correction, will be determined. Figure 6 shows on DEM corrected nadir and backward images.

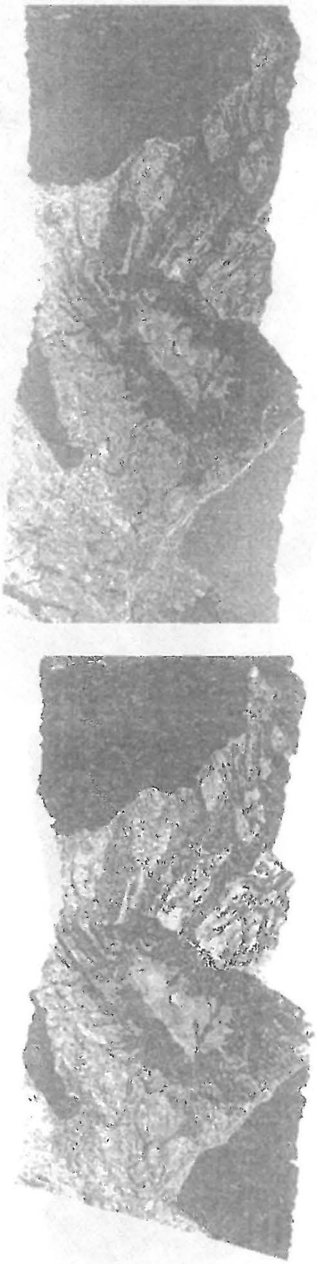

Figure 6 Corrected nadir (top) and backward (bottom) line

In Figure 7 a perspective view from north to south over the Rigi region is seen. The image data are from the corrected nadir data.

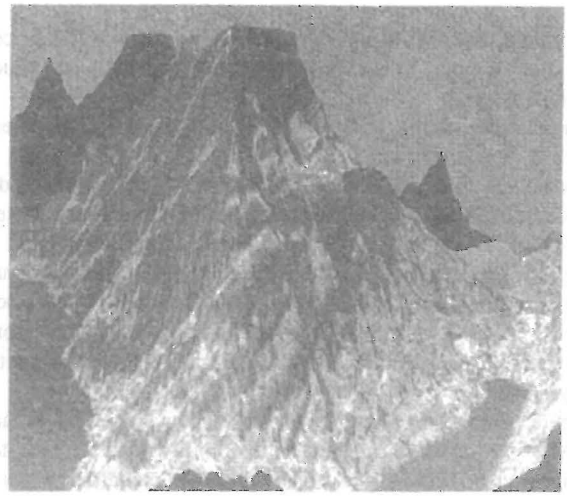

Figure 7 View over Rigi region

With the knowledge of the intersection point, the grey value of the pixel of the original image at a certain position will be put to a new position into the corrected image. This position can be calculated from the x-y coordinates of the intersection point. The resolution of the output image can be considered. All pixels hitting one element in the corrected image will be added, and at the end the mean value of all these pixels will be calculated.
At this step a radiometric correction could be performed. The grey value should be changed in dependence on the atmosphere, on the sun position, and on the slope of the terrain.
In its dependence on the accuracy of the attitude data and on the resolution of the given DEM the corrected image corresponds to an orthophoto. Figure 8 shows a section of a corrected WAAC image which is combined with a map.

Figure 8 Overlay of map over a corrected WAAC image

4.3 Coregistration of the DAIS 7915 data

To shield the DAIS scanner from aircraft vibrations it is placed on shock mounts. These shock mounts cause additional attitude disturbances.
For the coregistration of the DAIS 7915 data a matching between WAAC and DAIS is carried out.
For the matching procedure a synthetic panchromatic band is derived from the DAIS bands to resample the radiometric characteristics of the respective WAAC bands. The DAIS band is registered to the original (uncorrected) WAAC nadir image, using a correlation algorithm. A direct matching to the attitude corrected WAAC image is impossible because of the strong perspective distortions over the whole image, caused by the topography.
Figure 9 shows sections of the uncorrected images of WAAC and DAIS with matched points. The distribution of the conjugated points in both images is caused by the additional disturbances in the DAIS image.

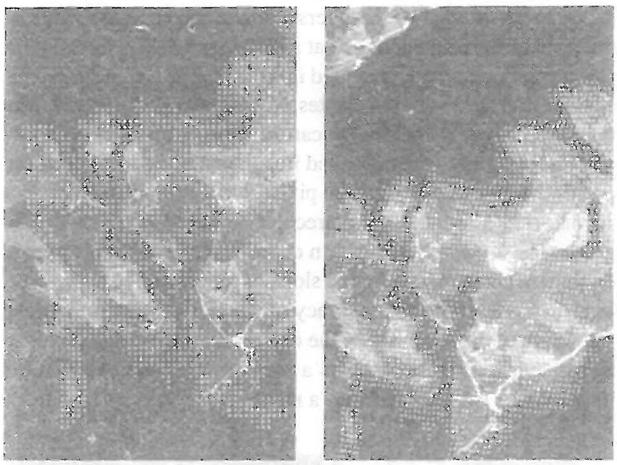

Figure 9 Additional disturbances in the DAIS image (right)

After the matching a parametric relation for each scan line between the uncorrected WAAC pixel and the DAIS pixel is done. With the corrected WAAC image and the knowledge of the original position of each pixel in the uncorrected image a correction of the DAIS image can be performed.
Using this approach DAIS images can be geometrically corrected and absolute oriented.
Figure 10 shows the corrected WAAC image of the nadir line and the corrected DAOIS image.

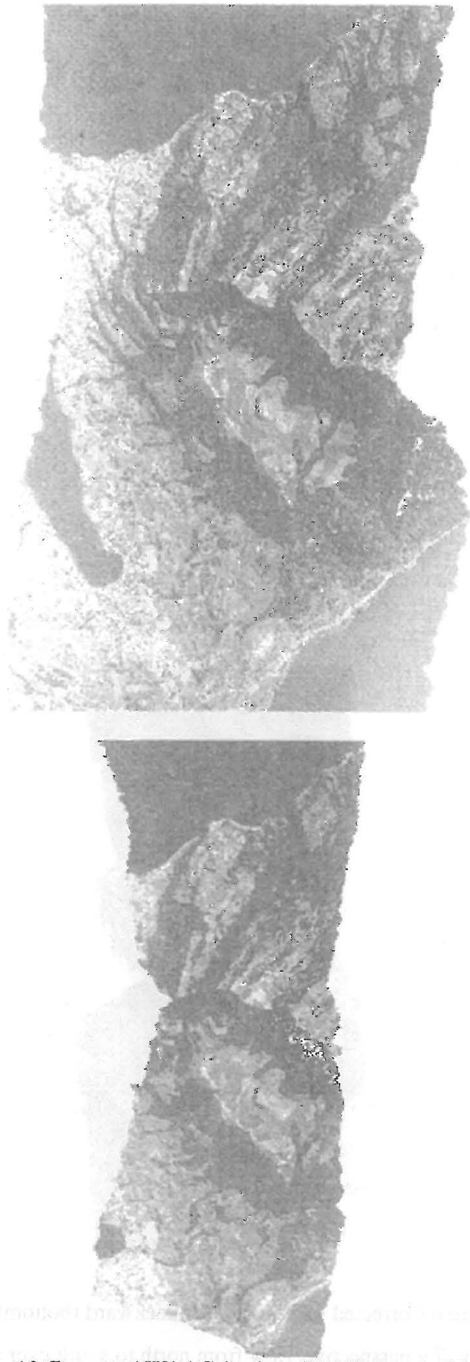

Figure 10 Corrected WAAC (top) and DAIS (bottom) image

5 CONCLUSIONS

The paper describes an approach for georeferencing of digital line scanner images. With this the generation of orthoimages, necessary for map projections, shown in chapter 3.4 is possible. Additionally the correction and coregistration of images with different panchromatic and spectral characteristics as well as geometric behaviour (field of view, resolution, view angle) can be performed.

Especially the multisensor approach in acquisition and processing presented here is capable of producing coregistered DEM's together with high spatial resolution stereo data and high spectral resolution data. Such data sets yield a high potential for a variety of interdisciplinary studies.

As a major advantage, all ground information required for a combined correction of atmospheric and topographic effects is readily available in digital format and appropriate accuracy.

Together with maps and other available ground information these airborne acquired data package constitutes a multipurpose GIS which will be most expedient for applications in ecology, exploration and land management.

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7 REFERENCES

A. Börner, R. Reulke, M. Scheele, T. Terzibaschian, "Stereo Processing with Attitude-Disturbed Image Data", International Archives of Photogrammetry and Remote Sensing, Vol. XXXI, part B3, pp. 686-691, 1996

S. H. Chang, M. J. Westfield, F. Lehmanm, D. Oertel, R. Richter, "79 - Channel Airborne Imaging Spectrometer", SPIE, Vol. 1937, pp. 164 - 172, 1993.

P. Meyer, "A Parametric Approach for the Geocoding of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Data in Rugged Terrain", Remote Sens. Environ., Vol. 49, No. 2, p. 120, 1994

C. Proy, D. Tanre, P. Y. Deschamps, "Evaluation of Topographic Effects in Remotely Sensed Data", Remote Sens. Environm., Vol. 20, pp. 21-32, 1989

R. Sandau, A. Eckardt, "The Stereo Camera Family WAOSS/ WAAC for Spaceborne / Airborne Applications", International Archives of Photogrammetry and Remote Sensing, Vol. XXXI, part B1, pp. 170-175, 1996

M. Schaepman, D. Schläpfer, A. Müller, P. Strobl, "Ground Spectroradiometric Measurements in Support of the Validation of the Calibration of Digital Airborne Imaging Spectrometer (DAIS 7915) Data", Presented at the Third International Airborne Remote Sensing Conference and Exhibition, 7-10 July, 1997, Copenhagen, Denmark

M. Scheele, T. Terzibaschian, "Attitude and positioning measurement system used in the airborne testing of the original Mars Mission Wide-Angle Optoelectronic Stereo Scanner WAOSS", International Archives of Photogrammetry and Remote Sensing, Vol. 30, Part 1, 1994, pp. 47

P. Strobl, R. Richter, F. Lehmann, A. Müller, B. Zhukov, D. Oertel, "Preprocessing for the Airborne Imaging Spectrometer DAIS 7915", SPIE Proc. Vol. 2758 pp. 375-382, 1996

P. Strobl, A. Müller, D. Schläpfer, M. Schaepman: "Laboratory Calibration and Inflight Validation of the Digital Airborne Imaging Spectrometer DAIS 7915 for the 1996 Flight Season", SPIE Proc. Vol. 3071, 1997 in press

R. Richter, "Correction of atmospheric and topographic effects for high spatial resolution imagery", Int. J. Remote Sensing, 1997, Vol. 18, pp. 1099-1111

N. Reulke, R. Reulke, M.Schaepman, D.Schläpfer, P.Strobl, A.Mueller, Combined Processing and Evaluation of Simultaneously Acquired Stereo and Hyperspectral Scanner Data, Proceedings of the Third International Airborne Remote Sensing Conference and Exhibition, Vol. II, pp. 329, 1997