THE HRSC/WAOSS CAMERA EXPERIMENT ON THE MARS96 MISSION – A PHOTOGRAMMETRIC AND CARTOGRAPHIC VIEW OF THE PROJECT

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ABSTRACT

A Russian mission to planet Mars is scheduled to be launched in November 1996. The operational orbit around Mars will be entered in autumn 1997. The spacecraft carries a German camera experiment comprising the HRSC (High Resolution Stereo Camera) and the WAOSS (Wide Angle Optoelectronic Stereo Scanner). It is the first time that such an experiment has been designed according to the special requirements of stereophotogrammetry and planetary mapping. Therefore it will provide a powerful tool for photogrammetric, cartographic and geoscientific investigations of the planet. The international Science Team involved is guided by Prof. Gerhard Neukum as Principle Investigator.

The paper gives a general outline of the experiment and the most important technical parameters of the cameras. Both cameras are designed as three-line scanner instruments in order to enable stereophotogrammetric evaluation of the data. The systems have already been subject to detailed calibration and testing. For photogrammetric restitution of the image data, generation of DTM's and orthoimages, and for the derivation of all types of cartographic products as well a comprehensive software package is being developed. Special reference systems for digital data handling and for cartographic purposes have been defined. Furthermore a new map series for the planet Mars, the »Topographic Image Map MARS 1:200 000« has been designed.

1. THE MARS96 MISSION

The Russian mission Mars96. which is scheduled for launch in November 1996 will enter its operational orbit around the planet in autumn 1997. Due to power aspects a highly elliptical orbit with distances to the planets surface varying from about 300 km to nearly 22,000 km will be flown. This enables operation for about one Martian year (which is two years on Earth). The spacecraft will carry a number of instruments serving a variety of scientific experiments. Several instruments are adapted to an adjustable platform called ARGUS.

Germany contributes two cameras to be flown on the ARGUS platform, namely the HRSC (*High Resolution Stereo Camera*) and the WAOSS (*Wide Angle Optoelectronic Stereo Scanner*). The camera experiment is guided by the Principle Investigator Prof. Gerhard Neukum, German Aerospace Research Establishment (DLR), Institute for Planetary Exploration in Berlin-Adlershof. It will provide a powerful tool for photogrammetric and cartographic purposes, for geoscientific investigations, and for studies of the atmosphere as well (Albertz et al. 1992). In the following photogrammetric and cartographic aspects are emphasized.

2. THE CAMERAS HRSC AND WAOSS

The main objectives of HRSC and WAOSS as defined by the team of Co-Investigators are to improve our knowledge and understanding of the shape, structure, and evolution of the planet Mars in terms of geoscience, photogrammetry and cartography, as well as the structure and dynamics of its atmosphere. Unfortunately, the photogrammetry, cartography, and geodesy aspects were poorly covered by previous missions to Mars. This is why the Mars96 camera experiment was especially designed to provide the following capabilities:

- imaging at high resolution of better than 15 m/pixel,
- stereo imaging of the Martian surface and of atmospheric clouds at various scales,
- multiple area coverage (to monitor dynamical phenomena),
- multispectral imaging (to study the composition of surface materials),
- multi-phase angle imaging (to study physical properties and weathering states of surface materials), and
- limb sounding.

This has led to the concept of two different muti-sensor instruments: the HRSC principally designed for investigations at local to regional scales panchromatically and in four narrow-band colors, and the WAOSS designed for global coverage and for panchromatic observations of time-dependent phenomena. The unique advantage over previous imaging experiments from Mars orbits is in the simultaneous stereo, spectral, and photometric coverage by combined operation of the two sensors. For some technical parameters see Table 1.

Parameter	HRSC	WAOSS
Focal length	175 mm	21.7 mm
Number of CCD lines	9	3
Active pixels/CCD line	5184	5184
Radiometric resolution:		
A/D converter bits	10 bit	11 bit
Bits entering compression	8 bit	8 bit
Field of view	11.9°	80.0°
Stereo angle (convergence)	18.9°	25.3°
Swath width*	62 km	519 km
Maximum ground resolution*	12 m	97 m
Weight	24 kg	7 kg

* for flying altitude 300 km at the pericenter

Table 1: Technical parameters of HRSC and WAOSS

Both instrument designs benefit from the experience gained from previous three-line stereo cameras and hybrid technology electronics. Thus, both cameras use multiple CCD line detectors mounted in parallel. These CCD sensors are installed on focal plate modules which are almost identical for both cameras. Modern high-reliability hybrid technology has permitted the incorporation of miniaturized sensor electronics.

2.1 High Resolution Stereo Camera (HRSC)

The HRSC instrument is a high resolution CCD scanner with nine CCD lines providing multiple along-track stereo imagery as well as colour information and high resolution image data (up to 12 m/pixel). It was designed at DLR and the main contractor for its production is the Dornier company in Friedrichshafen, Germany. HRSC is optimized for local and regional coverage of preselected surface areas. Typically, image strips of more than 300 km length will be collected. These strips will be recorded as overlapping data takes by 9 separate sensors (3 panchromatic stereo sensors, 4 multispectral sensors, and 2 additional photometric sensors). After ground data processing, the image data will yield high resolution, stereo capability, and thematic information.

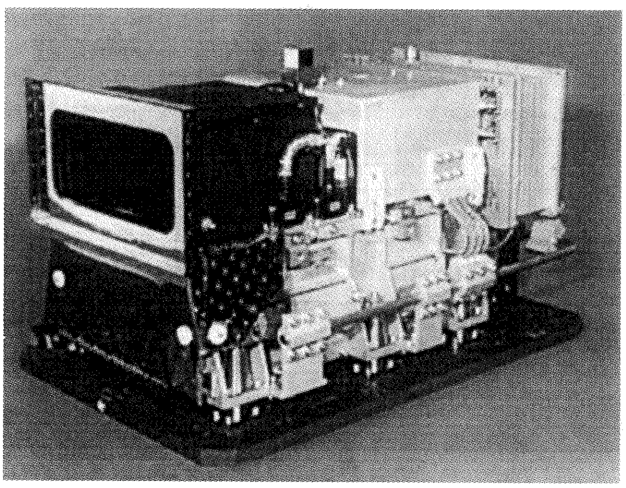

Fig. 1: General view of the High Resolution Stereo Camera (HRSC)

The imaging parameters for each exposure sequence have to be commanded in advance. Owing to the different viewing angles of the individual sensors within the HRSC focal plane, the sensor data have to be activated and deactivated sequentially to obtain overlapping ground coverage. In addition, the sensor exposure times have to be adapted to the varying spacecraft velocities and heights along the elliptical orbit.

2.2 Wide Angle Optoelectronic Stereo Scanner (WAOSS)

WAOSS was designed for wide angle scanning of the Martian surface and atmosphere. Three CCD line sensors provide panchromatic wide angle stereo coverage. WAOSS permits on-line adaptation of sensor exposure times, signal level normalization, pixel binning and compression rates. In contrast to the multi-box concept of HRSC, WAOSS was conceived as a compact single box instrument with integrated baffle, optics, spectral filters, power converter, 3 CCD line sensors, sensor electronics, and a digital unit for interfacing, data handling, image data preprocessing and compression.

The wide angle conception of WAOSS with its three CCD lines again enables along-track stereo capability but with a much larger field of view. Thus global coverage of the planet Mars with a ground pixel size of 100 m/pixel and larger can be realized.

2.3 Camera Calibration and Tests

The design goals, in particular photogrammetry and spectrophotometry, impose strong requirements on the geometric and radiometric precision ot the two camera systems. Therefore, a thorough calibration of the different flight models of the two camera systems was started in 1994. The calibrations are being conducted in three stages, the pre-calibration of the focal plate subunit, the radiometric calibration of the camera head (which includes the optical system), and the geometric calibration of the camera head. Calibrations for HRSC were done at the DLR Oberpfaffenhofen facility and the Dornier laboratory in Friedrichshafen. WAOSS is being calibrated at the DLR-Berlin-Adlershof facility.

Outdoor tests of the cameras were conducted in spring 1995 to verify proper combined operations of both cameras and to test their imaging performance. Both cameras were installed on a turn-table which was rotated at a rate that matched the scan rate of the cameras to simulate spacecraft motion. The first images were obtained from the Dornier campus near Friedrichshafen with viewing across Lake Constance and the Swiss Alpes near the Säntis mountain (Fig. 2). The image data of HRSC and WAOSS were compressed in such a way that compression factors of approximately 5 - 8 were normally achieved. However, higher compression rates of up to 40 were also achieved to allow a study of the interdependence of data compression and image quality.

In addition, WAOSS was also tested inflight. Some airborne tests have been flown over brown coal surface mining areas and urban regions as well (Fig. 3). Even an inside view of a cathedral could be generated demonstrating the wide dynamic range of the WAOSS data.

Laboratory and outdoor test of the flight modules indicate that the cameras meet or exceed their design goals. In particular the high resolution capabilitiy of HRSC and the dynamic range of WAOSS yielded impressive results. Thus very high quality image data from Mars mission can be expected.

3. REFERENCE SYSTEMS FOR PHOTOGRAMMETRY AND CARTOGRAPHY

The potential of the combined HRSC/WAOSS experiment will open a new era in mapping of the planet Mars. The accuracy of point determination and DTM generation will considerably improve our existing knowledge. This is why there was also a need set new definitions for the reference systems to be applied for photogrammetric and cartographic activities.

This issue has been subject to many discussions during the meetings of the Photogrammetry and Cartography Working Group (PCWG). Finally the following definitions were accepted.

3.1 Planetocentric Coordinates

The establishment of a geodetic control network, photogrammetric bundle adjustment etc. will be based on a planetocentric coordinate system (Fig. 4). Any point P on the Martian surface can be described by

- its *planetocentric latitude* φ, this is the angle between P, the planet's center and the equatorial plane (φ is positive in the northern hemisphere),
- its *planetocentric longitude* λ, this is the angle between the meridian through P and the prime meridian ($\lambda = 0$) through the crater Airy-0 (λ counts positive towards the east),
- its *distance* R, this is the radius vector from the center of mass (origin of the system) to the point P.

3.2 Planetographic Coordinates

For all mapping activities a reference body fitting appropriately to the shape of the planet need to be defined. Following the traditional understanding in mapping science and in accordance with the already existing maps, it was decided to define planetographic coordinates as the primary reference system for mapping. According to the definitions generally accepted by the International Astronomical Union (IAU) a planetographic system is associated with longitudes counting positive to the west. This is why the map coordinates of a point P will be

- the *planetographic latitude* φ', this is the angle between the normal to the reference surface at P (generally an ellipsoid) and the equatorial plane (φ' is positive in the northern hemisphere),and

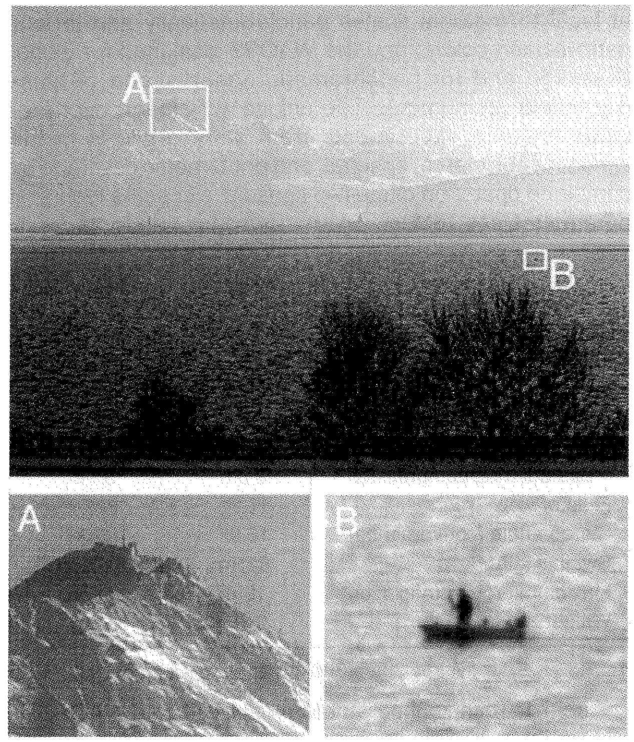

Fig. 2: HRSC test image, acquired in Friedrichshafen across Lake Constance. The top image is a small subset of an original image strip. The lower images show details, namely the Säntis Peak at a distance of 43 km and a fisher boot on Lake Constance.

Fig. 3: Part of an image strip acquired in July 1995 during a WAOSS test flight over Berlin (after first-order geometric correction)

- the *planetographic longitude* λ', this is the angle between the meridian through P and the prime meridian (λ' = 0) through the crater Airy-0 (λ' counts positive towards the west).

It is obvious that λ' and λ complement each other to 360°, whereas φ' and φ are more or less similar values.

The reference surface for mapping will be a spheroid, i.e. a bi-axial ellipsoid.

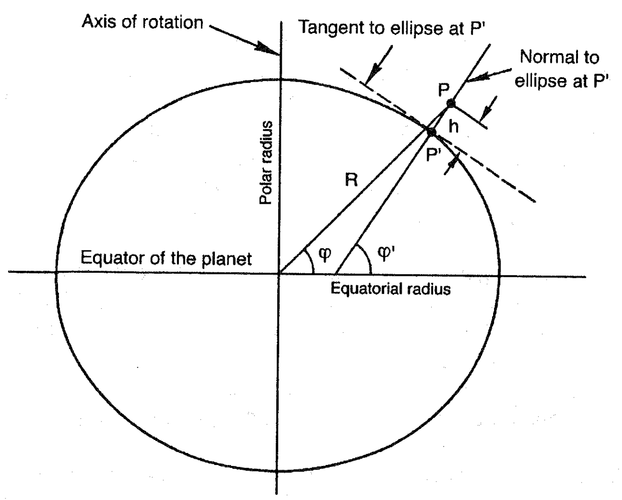

Fig. 4: Planetocentric latitude φ and planetographic latitude φ' of a point P

3.3 Definition of heights

It is still more difficult to define a reference system for height measurements, i.e. as an elevation reference level for DTM's and for the derivation of contour lines in maps. From a theoretical point of view an equipotential surface – such as the geoid on Earth – is supposed to be the best solution. However, the field of gravity on Mars is much more irregular than the geoid and its present knowledge is still very weak. It is therefore not sufficient for the definition of a height reference system.

On the other hand, the use of a mathematically defined reference surface offers some practical advantages. In particular it makes the height system independent from improved knowledge of the gravity field, and transformation between different coordinate systems is easy to handle. The most appropriate mathematical surface for this purpose is a tri-axial ellipsoid, which fits to the irregular shape of the planet significantly better than a bi-axial one. This is why it was decided to use DTM heights based on a tri-axial ellipsoid, with the height measured along the radius to the center of the planet.

This definiton implies that heights are not measured along a plumb line as we do on Earth, and that theoretically (virtual) water could run up-hill. However, the differences are estimated to be very small, and it is unlikely that this effect will ever be cartographically important.

4. PHOTOGRAMMETRIC AND CARTOGRAPHIC PROCESSING OF HRSC/WAOSS IMAGE DATA

In order to provide a wide range of different photogrammetric and cartographic products a comprehensive and mostly automated processing line has been set up. It is coordinated by the *Photogrammetry and Cartograpy Working Group* (PCWG) of this camera experiment under the chairmanship of Prof. Jörg Albertz, Technical University of Berlin (TUB).

Software development has to consider that the image formats of the HRSC and WAOSS data are fundamentally different from common sensor sytems. Different commanding strategies allow many variations within one imaging sequence, which makes the development of adequate software components complicated. Variable aspects within one data set are the starting sample positions on CCD, the number of samples per line and the pixel resolutions because of the elliptical orbit and also the formation of so-called macropixels.

4.1 Photogrammetric Point Determination

The photogrammetric investigations in order to generate high accurate orbit and attitude information derived by photogrammetric bundle block adjustment are guided by Prof. Heinrich Ebner, Technical University Munich (TUM). This fundamental basis for all further processing operations will be generated using the original orbit and attitude data as well as the data of the existing horizontal and vertical control network.

In order to prepare for this task computer a great deal of simulations on block triangulation have been performed to obtain a survey of the attainable accuracy and to give recommendations in the planning phase of the Mars96 mission. Comprehensive simulations on local, regional and global point determination based on HRSC and WAOSS imagery and orbit parameters as well have been conducted by Ohlhof (1995).

It turned out that local point determination from HRSC data can be considerably improved if the two photometric channels of the camera are incorporated into the bundle adjustment.

Regional and especially global point determination greatly benefit from the combination of HRSC and WAOSS imagery. For the root mean square values of theoretical standard deviations of adjusted object point coordinates the relations in Table 2 were derived.

Camera	x/y	z
HRSC (3 CCD lines)	9.1 m	28.7 m
WAOSS (3 CCD lines)	42.2 m	82.6 m
HRSC + WAOSS (3+3 CCD lines)		
• all points	28.7 m	56.1 m
• HRSC + WAOSS points	3.4 m	13.8 m
• WAOSS points	36.0 m	69.9 m

Table 2: Rms values of theoretical standard deviations of adjusted object point coordinates (from Ohlhof 1995)

In summary it can be stated from the simulation studies, that the synergy effect of image and orbit information is most effective. It can be expected that the accuracy of the current ground control network of Mars will be generally imroved by a factor of ten or more. Still more sophisticated adjustment procedures, considering also Mars rotation parameters, are being developed. For details see Ohlhof (1995, 1996).

4.2 Generation of Digital Terrain Models

The Technical University of Berlin is responsible for the following steps of the photogrammetric/cartographic processing line, e.g. the generation of local, regional and global Digital Terrain Models (DTM). To fulfill this task an extended area based least squares matching technique has been developed (Wewel 1996), which makes use of the entire set of possible multiple image data (along and across track) in one process in spite of only two images as it is done in conventional stereo approaches.

Afterwards a Digital Terrain Model (DTM) is derived by multiple ray intersections making use of the conjugate points information that resulted from the matching process. In areas where matching was not sufficiently successful shape-from-shading techniques will be used to fill the gaps. The irregular grid of the primary DTM is converted to a regular DTM grid through appropriate interpolation (Uebbing 1996).

The planimetric reference surface for the DTM is the same bi-axial ellipsoid which also serves for mapping purposes (see chapter 3.2). Spacing is performed in a similar way as it is required for mapping procedures in the sinusoidal projection. However, heights are handled according to the definition described in chapter 3.3, i.e. they referr to a tri-axial ellipsoid as a reference level.

4.3 Orthoimage Generation and Mosaicking

Based on DTM information orthoimages and image mosaics will be derived by completely automated processes which have also been developed at the Technical University of Berlin. While common orthoimage or mosaicking techniques require manual interactions (e.g. to identify control points for rectification or to define overlapping regions and borderlines between adjacent images) these new tools depend only on the accuracy of the orbit and attitude information.

At the end of the photogrammetric processing line high quality colour data sets will be generated by merging multispectral image data of three colour channels and the high resolution panchromatic data through RGB-IHS-RGB colour transformations.

The software developed for automatic orthoimage production and mosaicking has already successfully been tested with existing planetary data sets. Mosaics e.g. of up to 3000 images of the Moon have been generated from data of the Clementine mission. For details see Scholten (1996).

5. MAP PRODUCTS

The camera experiment on the Mars96 mission is expected to provide a great amount of image data. Its mapping potential will by far exceed what has been possible so far. This is not only because of the regional and global coverage of stereo imagery, the availability of high precision DTM's but also due to a considerably improved geodetic control network. Thus, a completely new situation for mapping the planet in high-quality topographic maps can be envisaged.

The data that is expected to become available during the mission is applicable for the generation of maps in scales between 1:500 000 and 1:50 000. The techniques to be applied for map production are of course digital cartographic approaches.

This situation gives rise to define the details of new map series. According to the potential of the camera experiment and in particular the spatial resolution of the image data the scale 1:200 000 was selected for the primary map series. The type of map will be a combination of image map and topographic map. Therefore the new map series was named »*Topographic Image Map MARS 1:200 000*«.

The map projection selected for this project is the Sinusoidal Projection due to the fact that it is an equal area projection and a variety of other practical advantages. The polar regions, however, can only appropriately be mapped in azimuthal projections. The Lambert Azimuthal Projection has been selected because it is also an equal area projection.

The parameters of the new map series have been determined. The entire planet was devided into several latitude ranges, each with a special map sheet dimension in terms of latitude and longitude, resulting in more than 10,000 map sheets. For details see Lehmann (1996).

The working group is well aware of the fact, that shadows can be a serious problem in the production of image maps under the conditions of this project. Therefore attempts are being made to apply »deshading« and »reshading« operations in order to achieve hill shading effects as they are desired in topographic cartography. Prof. E. Dorrer and Prof. G. Neugebauer are working on this problem.

6. OUTLOOK

The camera experiment on the Mars96 mission will provide a powerful tool for photogrammetric and cartographic applications of the data. The photogrammetric restitution, the generation of DTM's and orthoimages as well as the production of completely new map series of the planet is a great challenge for the people involved. They do their best to make the mission a success. And they hope, that a large scientific community will considerably benefit from this project.

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