THE CAMERA EXPERIMENTS HRSC AND WAOSS ON THE MARS 94 MISSION

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ABSTRACT:

The High Resolution Stereo Camera (HRSC) and the Wide-Angle Optoelectronic Stereo Scanner (WAOSS) are remote sensing instruments of the ARGUS platform to be flown onboard the Russian Mars 94 spacecraft.

The main objectives of the HRSC experiment are to acquire stereo image data, to derive detailed digital terrain models and orthophotos, to examine morphological features, geological processes and surface-atmosphere interactions. The camera will be operating in nine channels with different inclinations, different geometric resolution, and different spectral bands. The highest geometric resolution of 10 m/pixel will be achieved at an altitude of 250 km at periapsis.

WAOSS will also acquire stereo image data using a similar camera design. It consists of three panchromatic channels comprising two inclined stereo views with 80 m resolution at periapsis. The main interests in interpretation of WAOSS data are the examination of major atmosphere and large-scale surface phenomena.

The paper describes the concepts and the specifications of the cameras and the approaches for processing of the data. Main emphasis is laid on photogrammetric and cartographic processing.

KEY WORDS: HRSC, WAOSS, Stereo Cameras, Photogrammetry, DTM, Extraterrestrial Mapping, Mars

1. INTRODUCTION

1.1 Planetary Remote Sensing

Since decades satellite remote sensing is applied for mapping and monitoring of the Earth's surface. Data acquisition as well as data processing is highly developed and also standardized for the well known scanners Multispectral Scanning System (MSS) and Thematic Mapper (TM) onboard Landsat and the HRV instruments on the SPOT satellites.

Characteristic features of these systems are high data quantities by operational service for nearly the complete Earth's surface and high quality by combining good geometric resolution (down to 10 m/pixel) and multispectral capabilities. Stereo data as input for the generation of DTMs can only be achieved through SPOT image data with oblique viewing from adjacent orbits.

In planetary science remote sensing has also a long tradition (Neukum et al., 1984). Various spacecrafts carried imaging systems to other planets and to the borders of our solar system (e.g. Mariner, Viking, Voyager and the Soviet Venera missions).

With regard to mapping of Mars especially the US missions Mariner 9 and Viking were very successful, although the image data by far do not reach the quantity and quality of data from the Earth observing systems mentioned above.

Image data from the Mariner-9-mission cover the whole planet but only with a resolution of about 1 km/pixel. Viking imagery improved the geometric resolution so that about 90 % of the Martian surface is known in a resolution of 100 - 150 m/pixel. Very few small regions are covered with higher geometric resolution up to 6 m/pixel. Beside the geometric aspects Viking imagery is restricted by its radiometric properties. Multispectral imagery can only be derived by combining three different data sets of the same region with similar viewing and camera conditions.

It is also possible to derive stereo information using Viking Orbiter data. However, the Viking missions were not designed to acquire stereo images systematically. Therefore only a few stereo pairs, often showing significant differences in scale between the two images, became available and only small regions could be mapped in detail. This is why the already existing geodetic control network and the Digital Terrain Model (DTM) for the complete planet are of low accuracy (about ±1 km).

Another experiment, the Mars Observer Camera (MOC) on the Mars Observer mission (scheduled to launch in September 1992), will also acquire images of the surface and atmosphere of Mars. MOC will yield complete coverage of the planet at approximately 7.5 km/pixel and will acquire high resolution image data at approximately 1.4 m/pixel for small regions of 2.8 km × 2.8 km. Nevertheless, MOC will not fulfill the science objectives of the Mars 94 experiments, because it will not have stereo capability.

1.2 Objectives of the Mars 94 Camera Experiments

Despite many scientific achievements there remain many open questions about the evolution and history of the Red Planet, which can be directly addressed by the High Resolution Stereo Camera (HRSC) and Wide-Angle Optoelectronic Stereo Scanner (WAOSS) imaging experiments (Neukum et al., 1990; Oertel et al., 1991). The quality of imagery and the coverage of Mars by the combination of HRSC and WAOSS is expected to be much superior to the Viking ones and will open a new domain of detailed scientific investigation of Mars at a local and regional scale. The HRSC multisensor experiment will allow to image parts of the Martian surface down to 10 m resolution in combination with stereo and multispectral information.

The methods that will be used for the evaluation of the HRSC and WAOSS data after systematic image processing are those of

- Photogrammetry,
- Cartography,
- Photoclinometry (also called shape from shading),
- Spectrophotometry, and
- Photogeology.

For the interpretation of the Martian topography, for understanding the processes which formed the different surface morphologies, and for the selection and verification of future landing, three dimensional information is absolutely necessary. It must be one of the top-priority goals of any future Mars mission to obtain such information. Only in this way we can hope to come closer to deciphering the geologic history of Mars. Besides this the WAOSS stereo images will give the opportunity to monitor atmospheric processes. Weather observations, the estimation of cloud dimensions and velocities and even the development of dust storms will be subject to scientific investigations.

Therefore, in the HRSC and WAOSS experiments emphasis is given to the acquisition of adequate data for deducing information concerning the Martian topography and atmosphere. This will be possible by the unique feature of both experiments, the 3-line stereo viewing capability, and the photometric and colour information of the HRSC images. In the first case, methods of digital photogrammetry will be applied; in the second case, new photometric models of the diffuse reflection of the Martian surface will be used to derive information on local slopes (photoclinometry) and on local surface material. A new approach is the combination of results from digital photogrammetry and photoclinometry of the HRSC experiment in order to produce digital terrain models which are expected to be superior to those derived by either method separately.

1.3 Participants in the Experiments

As part of the Mars 94 mission the HRSC and WAOSS experiments define the German contribution to this multinational space research project. The Principal Investigator for the combined HRSC/WAOSS experiment is Prof. Dr. G. Neukum from the German Aerospace Research Establishment (DLR). Among other obligations he is responsible for the scientific guidance of the experiments and the coordination of the different working groups involved.

So far the DLR in Oberpfaffenhofen near Munich was responsible for the experiment coordination and the development of the HRSC instrument which is manufactured by a private company. The WAOSS camera is being developed and produced at the DLR institute in Berlin-Adlershof, the former GDR Space Research Institute (IKF). Since early this year the camera experiments were combined and the DLR working group of Oberpfaffenhofen moved to Berlin. This is why the complete project is now organized by the new institutes of DLR at Berlin-Adlershof.

The camera experiments found a widespread interest in the scientific community. Therefore an interdisciplinary science team will contribute to the evaluation and interpretation of the data. It comprises experts in planetary science, geology, geophysics, geomorphology, meteorology, etc. Photogrammetry and cartography are of central importance for the project.

The working group for photogrammetry and cartography for both experiments consists of the Department of Photogrammetry and Cartography at the Technical University of Berlin (TUB) represented by Prof. Dr.-Ing. J. Albertz as Co-Investigator, the Chair for Photogrammetry and Remote Sensing at the Technical University of Munich (TUM) represented by Prof. Dr.-Ing. H. Ebner as Co-Investigator, and, to ensure the integration with other scientific working groups of the experiments, a photogrammetry-oriented team of scientists at the DLR in Berlin-Adlershof. Main objectives of the photogrammetric/cartographic working group are the photogrammetric restitution, the generation of DTMs, the production of orthoimages and image maps as well as several follow-up products.

2. THE MARS 94 MISSION

2.1 The Mars 94 Spacecraft

The Mars 94 mission is part of a long term Russian Mars exploration program which extends beyond the year 2000. The present planning includes a number of separate missions, ranging from unmanned to possibly manned missions to Mars.

This mission is planned as a two spacecraft mission. For the Russian side the two spacecraft concept is a commonly used redundancy technique. As for observation conditions, it allows for comparative observations and, in case of full parallel observations twice the amount of returned data.

The present planning, however, is based upon a mission scenario with only one of the two spacecrafts being momentarily active (and the other spacecraft being activated alternatively).

The type of spacecraft is similar to that used during the Phobos mission 1989. Modifications have been made with respect to some mechanical structures and the control system. The spacecraft is (nearly) inertially stabilized with one axis pointing to the sun and another axis pointing to Canopus. As the position of Canopus lies 28° off the south pole of the ecliptic, the spacecraft wobbles slowly over the period of one Martian year.

The Mars 94 mission is characterized by an elliptic and highly eccentric orbit with a periapsis height of about 250 km (figure 1, Buma et al., 1991). Due to the oblateness of Mars, the orbit will drift leading to a variety of observing opportunities.

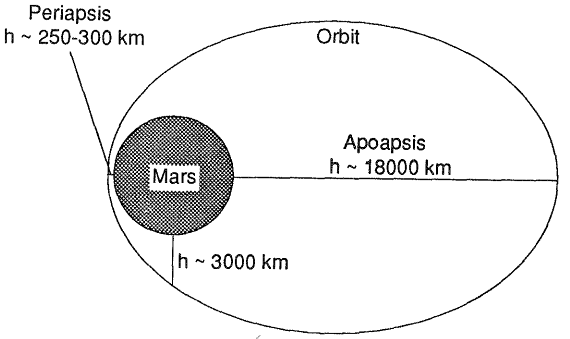

Figure 1: Spacecraft Orbit

For a spacecraft in such an elliptic orbit two main features have to be taken into account. First, the height above ground changes by a factor of 10 from the periapsis to the poles. For imaging instruments this leads to varying pixel sizes and coverage on ground. Second, the velocity of the spacecraft changes considerably (by a factor of 2). Both aspects influence the definition of the sensors read out cycles which have to be adjusted in order to avoid underscans (gaps) and to reduce overscans (overlaps) between scan lines.

Each spacecraft carries a number of scientific instruments. Some of them are integrated into the main spacecraft body or, like balloons and lander, installed within descenders which are jettisoned.

Imaging and navigation instruments are mounted on a deployable platform. This separate platform (called ARGUS platform) carries:

- the High Resolution Stereo Camera (HRSC),
- the Wide-Angle Optoelectronic Stereo Scanner (WAOSS),
- an Imaging Spectrometer (Omega-VIMS),
- a Navigation Camera (NC) and
- the Planetary Infrared Fourier Spectrometer (PFS).

The ARGUS platform has three drives for the control of its axes. During operation of its payload, the platform will be kept nadir looking thus avoiding the necessity for the platform instruments to provide mechanical pointing mechanisms. The platform provides mechanical and electrical interfaces as well as a controlled thermal environment.

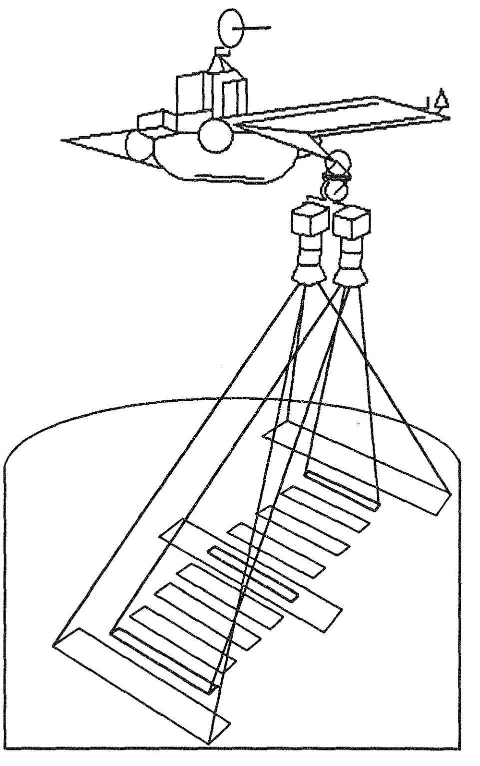

Figure 2: HRSC/WAOSS cameras on the Mars 94 spacecraft

2.2 The High Resolution Stereo Camera (HRSC)

The HRSC has been proposed by DLR in Oberpfaffenhofen (Department for Planetary Science) for detailed imaging of different phenomena on the Martian surface (Neukum & Tarnopolski, 1990; Neukum et al., 1990).

The main objectives of the HRSC experiment are to

- obtain stereoscopic views and terrain models of the Martian surface to examine the topography, surface relief and mass distribution of surface structures locally and regionally,
- systematically examine local areas at high resolution to determine morphological features, geological processes and surface/atmosphere interactions at a spatial scale down to 10 m,
- acquire high resolution image data for the production of digital orthoimages, image mosaics and image maps of high geometric accuracy and with multispectral information and
- to improve the geodetic control network of Mars.

A new feature of HRSC is its permanent stereo capability through the 3-line stereo concept. Full three dimensional information on the topography of the Martian surface can be derived from these images.

The HRSC camera concept is defined by three identical focal planes, each one consisting of three sensor arrays with 5184 active pixels. Together the three focal planes consist of one high-resolution panchromatic (clear) nadir channel (10 m ground resolution at periapsis), two panchromatic (clear) stereo channels with convergence angles of ± 19° (20 m ground resolution), four colour channels at ± 3° and ± 16° (40 m) and two additional channels at ± 13° (20 m) for photometric purposes (figure 3).

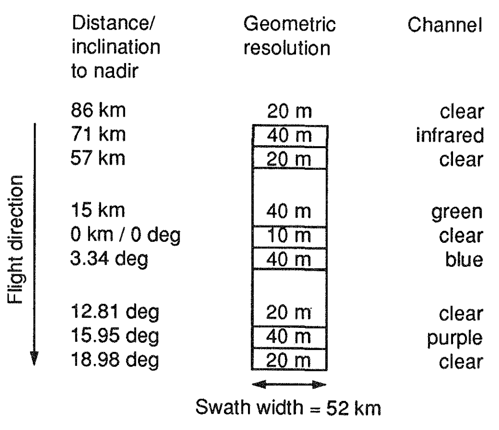

Figure 3: HRSC concept

Notice, that for HRSC in the following only the two scan lines at the convergence angles of ± 19° and the nadir line will be considered for stereo aspects. Nevertheless, it should be kept in mind that there will be six more colour or photometric scan lines available which can also be used for interpretation purposes, multispectral applications, and for improving the photogrammetric capabilities (e.g. in steep terrain).

However, as compared to photographic frame cameras used in airborne photogrammetry, the HRSC images possess separate orientation parameters (position and attitude) for each set of three scan lines, because of the dynamic image acquisition (push broom principle, Hofmann et al. 1982).

Mars's surface is imaged by HRSC by three scan lines differently inclined to the local vertical by instrumental convergence angles (forward looking, nadir and backward looking scan line, see figure 5).

The system generates three overlapping image strips of the Mars surface with parallel projection in flight direction and central projection within each scan line.

2.3 The Wide-Angle Optoelectronic Stereo Scanner (WAOSS)

The proposal for the second camera experiment, the WAOSS, came from the former GDR Space Research Institute (IKF) at Berlin-Adlershof, independently from the development of the HRSC experiment (Oertel et al., 1991). The basic purposes of WAOSS were the examination of cloud and dust storm movements and meteorological processes within the Martian atmosphere. After the integration of HRSC and WAOSS these tasks have been confirmed. Furthermore, WAOSS will have special capabilities, based on its camera design (see figure 2). This means that in the case of global mapping of the Martian surface topography the HRSC and WAOSS experiments complement one another to a powerful mapping tool. The wide coverage of WAOSS image data ensures that monitoring in different time scales will be possible.

Therefore the main objectives of the WAOSS experiment are to

- obtain global synoptic views of the Martian atmosphere and surface in order to study meteorological, climatological and related surface changes during the course of the mission,
- monitor global atmospheric phenomena over time scales of days, weeks, months, seasons and years,
- monitor polar cap phenomena,
- observe selected atmospheric phenomena at moderate resolution with alongtrack stereo capability,
- observe changes in selected surface features with alongtrack stereo capability and
- to generate DTMs and image maps at global and regional scales.

The WAOSS camera consists of one focal plane, identical to those used in the HRSC. There will be two panchromatic (clear) stereo channels at ± 25° and a panchromatic nadir channel with 80 m resolution at periapsis and with a slightly different spectral band (figure 4).

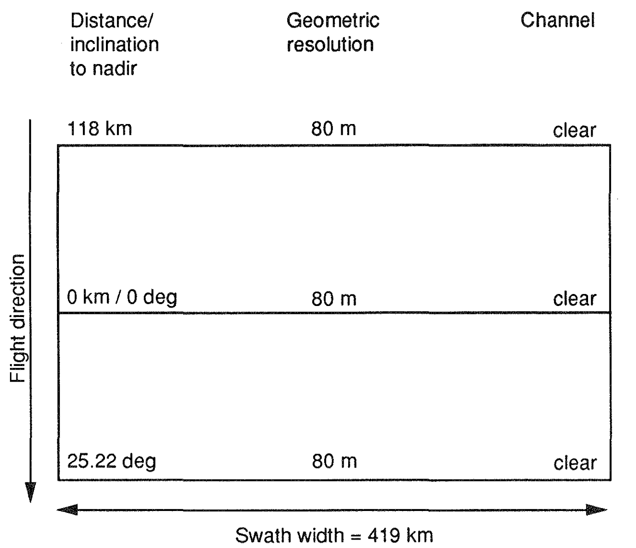

Figure 4: WAOSS concept in the scale of Figure 3

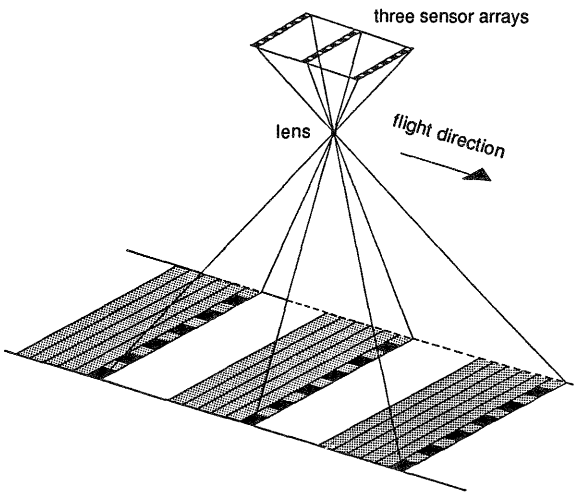

Figure 5: Viewing geometry

3. PHOTOGRAMMETRIC AND CARTOGRAPHIC PROCESSING

The procedures of photogrammetric and cartographic processing of the HRSC and WAOSS image data have to consider several factors, namely

- the lack of geometric reference data; the restitution and photogrammetric modelling processes will be based mainly on navigation data, conjugate points in the 3–line data and tie point information from adjacent strips,
- the elliptic and highly eccentric orbit; it will cause varying spacecraft velocities and viewing distances; the result will be that image strips show inconsistent geometric conditions,
- the 3-line concept of both cameras; it will provide triple coverage for stereo processing, a challenge for image orientation and image matching,
- the lack of high frequent image information; a huge part of the acquired image data will only show low texture; image matching will therefore need support by photoclinometric methods,
- changing illumination conditions during the mission; within the production of image maps, especially in the case of image mosaicking, shading methods will have to be examined.

The photogrammetric restitution and the studies on the integration of photoclinometry will be the tasks of the TUM (see also Heipke, 1992), whereas DTM generation, rectification, and cartographic processing will be performed by the TUB.

3.1 Photogrammetric Restitution

The photogrammetric restitution can be divided into two tasks, namely the automatic determination of conjugate points (image matching) and the photogrammetric point determination.

- *Automatic determination of conjugate points.* The determination of conjugate points in the image strips is a necessary prerequisite for any three dimensional evaluation of the data. Digital image matching techniques are an appropriate means to solve this task. Relevant methods can be classified into two main groups: area based and feature based techniques (e.g. Heipke, 1990). As compared to approaches developed for airborne images, some additional problems exist for the MARS 94 mission: (1) Wide parts of the images will show very little texture. In these parts the determination of conjugate points is only possible with low accuracy and reliability; (2) in order to simultaneously process HRSC and WAOSS imagery, a multi image approach must be designed which takes into account the different ground pixel resolution (10 m and 20 m as compared to 80 m) and the slightly different spectral bands; (3) image compression has to be performed in order to obtain a suitable data rate for transmission purposes. This compression will be based on the discrete cosine transform and result in a deterioration of the radiometric quality of the data.

  To fully exhaust the potential of digital image matching, a combination of feature based and area based techniques will be applied to determine the conjugate points. Furthermore image pyramids are incorporated into the strategy. In the first step point features and line features are extracted separately in each strip using image processing tools (Barnard et al., 1980; Förstner, 1986). These features are described by attributes such as minimum and maximum gradient, steepness of the autocorrelation function, etc. for point features, and the length and curvature for line features. Based on the attributes and on knowledge of approximate location of conjugate features these are then matched in a robust estimation process. The result is a list of conjugate features, from which conjugate points are extracted. In a second step area based matching is applied to obtain subpixel accuracy for the conjugate points.

- *Local, regional and global photogrammetric point determination.* The photogrammetric point determination, which includes the reconstruction of the exterior orientation of the digital imagery of the HRSC and the WAOSS cameras, represents a central task of the evaluation process in the experiments. It is the precondition for all subsequently derived information and products (e.g. DTM, digital orthoimages). The photogrammetric point determination is based on the principle of bundle adjustment. The three dimensional coordinates of object points and the parameters of the exterior orientation are simultaneously determined in a least squares adjustment from the following input data, which are considered as observations: (1) image coordinates of conjugate points; (2) elements of the interior orientation; (3) control information (e.g. ground control points (GCP), DTM information); (4) information concerning the exterior orientation parameters (position and attitude of the camera during time of recording).

  A major problem within the photogrammetric point determination in case of a deep space mission is the definition of the datum with high absolute accuracy. This task has to be solved using non-photogrammetric data like GCP, DTM information or absolute observations of the exterior orientation parameters. Since only inaccurate control information of the Mars surface is available, the absolute accuracy of point determination depends highly on precise measurements of the exterior orientation parameters.

The functional model of the photogrammetric bundle adjustment has to be further developed and adopted to the geometric conditions of the MARS 94 mission. This model has to take into account the above mentioned unknowns and observations.

The regional and global point determination will improve and extend the geodetic control network of Mars. It implies the simultaneous adjustment of a large number of image strips and must be based on a combination of HRSC and WAOSS data. Recent investigations for the MOMS-02/D2 project (Müller, 1991; Ebner et al., 1992) demonstrated, that the accuracy of point determination can be considerably improved, if a block of several overlapping strips is processed simultaneously in a bundle block adjustment. Flight passes of different flight directions yield the most accurate results. This effect is especially important for the MARS 94 mission due to the weak datum information.

3.2 DTM Generation and Rectification

As a result from the photogrammetric restitution the parameters of the exterior orientation will be provided for the generation of DTMs and the rectification. This process comprises the following steps:

- *Image matching for the determination of DTMs.* The derivation of a DTM requires a great number of conjugate points in the stereo data sets. In order to determine these point coordinates a combination of matching techniques must be applied. This includes the definition of candidate points by means of interest operators, the use of area based and feature based matching techniques (e.g. Li, 1990) and the application of plausibility tests. Depending on the data quality and the terrain types as well special treatment such as iterative approaches or interactive operations might be appropriate.

- *Derivation of DTMs.* From the image coordinates of conjugate points and the orientation parameters the three dimensional coordinates of the matched points are calculated. From these data a regular DTM will be derived by means of appropriate interpolation techniques.

- *Refinement of DTMs.* Furthermore it must be taken into account that matching is highly dependent on image texture. Therefore also the combination of photogrammetric and photoclinometric methods will be considered in less textured regions. This is part of the tasks of the TUM.

- *Rectification of the image data.* Based on the DTMs and the orientation parameters the image data will be rectified to orthoimages. The primary products are in black and white, using the HRSC or WAOSS nadir channel. Colour orthoimages can be generated if merging with other spectral bands (with less resolution) is applied, as it is generally the case in cartographic processing (see below). Because of the special geometry each spectral data set has its own exterior orientation, which has to be used for the rectification process.

- *Generation of follow-up products.* According to the needs of the HRSC/WAOSS Science Team different types of follow-up products can be generated such as contour maps, shaded reliefs, perspective views, profiles, slope maps etc.

3.3 Cartographic Processing

Cartographic data processing is closely connected and interrelated with parts of photogrammetric processing. However, the aspects of cartographic applications dominate the following procedures:

- *Mosaicking of individual scenes.* In general one map sheet can not be covered by a single scene. Therefore the different input scenes have to be mosaicked to one homogeneous data set (Albertz et al., 1987). With regard to the special geometry of HRSC or WAOSS data the mosaicking is connected with the bundle block adjustment where the orientation parameters of all scenes are computed simultaneously.

- *Conversion of the data to the particular map projection* selected for the related section of the planet's surface. The mosaicking of the image data and the transformation to the map projection can be achieved in a combined transformation, thus only one resampling process becomes necessary. Resampling is carried out in such a way that high frequency image details are preserved best.

- *Radiometric mosaicking.* Due to a variety of effects significant differences in radiometry occur between adjacent scenes (intensity, contrast and colour differences). Through radiometric mosaicking the data of several scenes are converted to one homogeneous data set. This is achieved by an approach which makes use of the multiple information within the overlapping areas of adjacent scenes. The iterative procedure developed for this purpose must be applied for each spectral band (Kähler, 1989). It has already been used for image map production with excellent results.

- *Image enhancement.* Image enhancement (e.g. by means of filter techniques) and adaptive processing will be applied in order to achieve best visual presentation in the final image map products.

- *Merging of image data sets* will be applied in order to combine panchromatic data, providing the high frequency information, and multispectral data, providing colour information. This technique has already achieved great importance in the production of terrestrial Satellite Image Maps (e.g. Tauch et al., 1990). Similar techniques must be applied to generate high quality image maps of the Martian surface.

- *Graphical processing* is required in order to generate cartographic products out of the image data. Additional informations such as lines, symbols, letters, numbers etc. have to be integrated in the image data (Albertz et al., 1992). Of particular interest is the integration of contour lines derived from the DTMs.

- *Generation of film originals.* For the production of image maps the resulting image data sets must be converted to film originals for printing. This is achieved by means of a large format high resolution raster plotter system, which transforms the grey values of the image data for each spectral band into a printing screen.

Experimental studies will be carried out for further development of the processing techniques and improvement of the products, centering on the following items:

- *Illumination problem.* It is very likely, that differences in illumination will be more irritating than is usually the case in terrestrial image maps. Therefore studies concerning the illumination of the terrain are necessary, especially experiments to remove shadow effects on the basis of the DTMs available.

- *Standardizing of illumination.* In some cases relief shading may be necessary in order to improve the interpretability of morphological features in the image maps. The results desired should be similar to the airbrushed maps in conventional planetary mapping, but much more objective.

- *Stereo-visualization of thematic data.* The digital approach offers new possibilities for the visualization of scientific findings in three dimensions. Through the combination of stereo image data and stereo-presentation of thematic data, synoptic views can be generated in order to improve analysis and interpretation techniques.

4. EXPECTED PRODUCTS

The products of the photogrammetry/cartography group will consist of highly resolved information for selected areas mainly using HRSC image data and of large areas covered by WAOSS image data with lower resolution. Substantial flexibility will be ensured to derive appropriate products of different resolution for the areas of particular interest. In detail it is anticipated to produce

- a Mars geodetic control network, considerably improved and extended by means of regional and global point determination. However, as yet the improvement in accuracy is difficult to predict.

- Digital Terrain Models of the particular areas with an accuracy appropriate to 1:50,000 topographic maps using HRSC information and DTMs at regional or global scale using WAOSS image data.

- Follow-up products to be derived from the DTMs such as contour maps, profiles, slope maps, perspective views etc.

- Orthoimages in black and white in different scales, derived by rectification from the image data of the nadir channels of both instruments and the determined DTMs.

- Image maps in colour with scales varying from 1:500,000 up to 1:50,000 for further interpretation and analysis and as base maps for thematic mapping.

- Topographic maps up to a scale of 1:50,000

- Thematic maps of various kinds according to the scientific goals and results from specific investigations of the entire science team.

5. OUTLOOK

The HRSC/WAOSS experiments are designed to meet present and future demands for topographic and thematic maps of the Martian surface. For these purposes

the image data will be converted to geometrically corrected standardized formats through photogrammetric and cartographic processing. Thus the image data will be made available to the scientific community for further analysis and interpretation, to support locating, processing and interpretation of other types of data, and as a base for the identification and visualization of scientific findings.

The timeline for the project is characterized by the following milestones:

- delivery of all flight instruments until mid 1993,
- spacecraft delivery to the launch facilities in spring 1994,
- spacecraft launch in fall 1994 (transfer to Mars in about 300 days),
- start of camera operations in October 1995 (scheduled mission duration is more than 700 days or one Martian year until September 1997),
- launch of the second spacecraft in fall 1996.

The development of the software package for photogrammetric and cartographic processing is scheduled to be completed at the end of 1994. The production line will be tested in 1995. The first products can be expected to become available in 1996.

The Martian surface nearly equals the land surface of the Earth. It is evident, that mapping such an area in medium or larger scales needs tremendous efforts and consumes large amounts of time and money. The HRSC/WAOSS experiments can not be understood as a complete mapping program in such scales. But a great step forward in mapping and a variety of other scientific results can be expected.

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