International Conference on Space Optics—ICSO 2000

Toulouse Labège, France

5–7 December 2000

Edited by George Otrio

The high resolution stereo camera (HRSC): acquisition of multi-spectral 3D-data and photogrammetric processing

Gerhard Neukum, Ralf Jaumann, Frank Scholten, Klaus Gwinner

International Conference on Space Optics — ICSO 2000, edited by George Otrio, Proc. of SPIE Vol. 10569
1056921 · © 2000 ESA and CNES · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307899

THE HIGH RESOLUTION STEREO CAMERA (HRSC) – ACQUISITION OF MULTI-SPECTRAL 3D-DATA AND PHOTOGRAMMETRIC PROCESSING

Gerhard NEUKUM, Ralf JAUMANN, Frank SCHOLTEN, Klaus GWINNER

German Aerospace Center (DLR)
Institute of Space Sensor Technology and Planetary Exploration
Rutherfordstr. 2, D – 12489 Berlin, Germany

email: Gerhard.Neukum@dlr.de
phone: ++49-30-67055-300, fax: ++49-30-67055-303

ABSTRACT *At the Institute of Space Sensor Technology and Planetary Exploration of the German Aerospace Center (DLR) the High Resolution Stereo Camera (HRSC) has been designed for international missions to planet Mars. For more than three years an airborne version of this camera, the HRSC-A, has been successfully applied in many flight campaigns and in a variety of different applications. It combines 3D-capabilities and high resolution with multispectral data acquisition. Variable resolutions depending on the camera control settings can be generated. A high-end GPS/INS system in combination with the multi-angle image information yields precise and high-frequent orientation data for the acquired image lines. In order to handle these data a completely automated photogrammetric processing system has been developed, and allows to generate multispectral 3D-image products for large areas and with accuracies for planimetry and height in the decimeter range. This accuracy has been confirmed by detailed investigations.*

INTRODUCTION

At the DLR-Institute of Space Sensor Technology and Planetary Exploration the HRSC was developed as a multispectral multi-line/multi-stereo scanner system for the exploration of Mars (Neukum & Tarnopolsky, 1990; Albertz et al., 1992; Neukum et al., 1995) and will be flown onboard the European Mars Express mission in 2003 (Neukum et al., 2000). A modified version has been established for airborne applications, the HRSC-A. It fulfils all radiometric and geometric requirements of a photogrammetric camera system and is equipped with a completely automated photogrammetric processing system, yielding highly accurate images and 3D-products (Wewel et al., 2000).

DATA ACQUISITION WITH THE HRSC-A

The High Resolution Stereo Camera (HRSC) is a multiple line pushbroom instrument. Nine superimposed image tracks are acquired simultaneously (along-track) by nine CCD line sensors mounted in parallel and behind one single optics. Five of these are panchromatic sensors arranged at specific viewing angles and provide the multiple-stereo and photometric capabilities of the instrument. Four of the nine CCD lines are covered with different filters for the acquisition of multispectral images. According to its development for space missions, the camera has small dimensions, low mass, low power consumption and a robust design. A slightly modified version of the instrument has been adapted for operation in terrestrial airborne remote sensing applications. To optimize image radiometry, the recording levels of the individual channels are controlled separately by adjustable gain factors.

	HRSC-A
Focal Length	175 mm
Tot. Field of View	38° x 12°
CCD Lines	9 (4 colors)
Stereo Angles	±18.9°, ±12.8°
Pixels / CCD Line	5184
Pixel Size	7 µm
Radiom. Resol.	8 bit
Scan Rate	450 lines/s
Stabilization	Zeiss T-AS platform
Data Recording	Sony high-speed data recorder
Geo Referencing	Applanix POS/DG Integrated dGPS/INS

Table 1. HRSC-A technical data

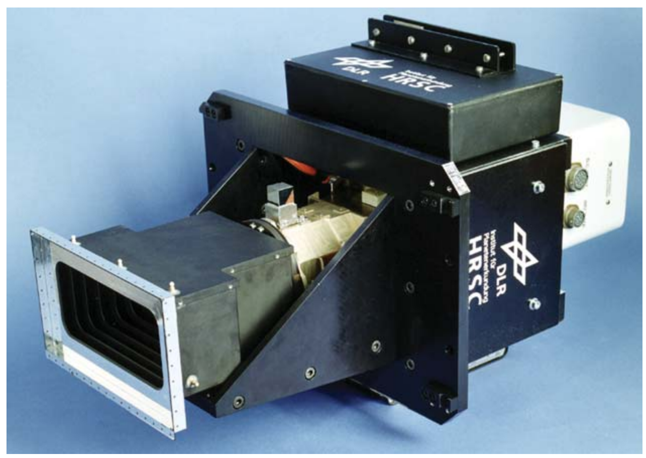

Figure 1. The HRSC-A

The HRSC-A (see Figure 1 and Table 1) is identical in its main structural features to the original (spaceborne) HRSC system and includes its original optics. Some additional electronics have been added to meet specific airborne requirements. During image acquisition, data rates of 10 MByte/s provided by four parallel signal chains can be stored on a high-speed tape recorder. The camera is mounted on a stabilized platform (ZEISS T-AS) in order to damp mechanical vibrations and to enforce near-nadir viewing. Position and orientation during flight navigation are measured continuously by means of differential GPS and INS.

Two further improved cameras have recently been introduced, HRSC-AX and HRSC-AXW (Table. 2, Fig. 2), which will provide even higher ground resolutions of up to 5 cm/pixel and wide-angle ground coverage.

	HRSC-AX	HRSC-AXW
Focal Length	151 mm	47 mm
Tot. Field of View	41° x 29°	30° x 79°
CCD Lines	9 (4 colors)	5 (2 colors)
Stereo Angles	±20.5°, ±12.0°	±14.5°, ±12.2°
Pixels / CCD Line	12172	12172
Pixel Size	6.5 µm	6.5 µm
Radiom. Resol.	12 bit	12 bit
Scan Rate	1640 lines/s	1640 lines/s
Stabilization	Zeiss T-AS platform	
Data Recording	Sony high-speed data recorder	
Geo Referencing	Applanix POS/DG integrated dGPS/INS	

Table 1: HRSC-AX/AXW technical data

Figure 2: The HRSC-AX

GPS/INS DATA PROCESSING

For the position and attitude determination of the HRSC-A camera the integrated GPS/INS system APPLANIX POS/DG is used. The Position and Orientation System (POS) consists of two components, the self-contained and separated Inertial Measurement Unit (IMU) and the POS Computer System (PCS). A high-performance Litton LR-86 IMU contains Litton A4 navigation grade accelerometers and Litton G7 dry-tuned gyros (DTG). The IMU is directly mounted on the top of an HRSC-A frame for precise measurements of camera motions. It provides data of incremental velocities and angular rates with an output data rate of 200 Hz. The POS also houses a GPS receiver L1/L2 Novatel Millenium Card while the GPS antenna is mounted directly above the HRSC-A camera.

The first step of post-processing is to combine raw GPS data from POS GPS receiver and from the ground reference station for a kinematic GPS solution. The second step of post-processing is the optimal integration of GPS and inertial data which was taken with APPLANIX software POSProc. The POSProc realizes an aiding inertial navigation algorithm, which combines the inertial data from the IMU with the GPS position and velocity to calculate highly accurate position and attitude. The resulting position accuracy is determined principally by the GPS solution and the attitude accuracy depends on the quality of the IMU inertial sensors. After the GPS/Inertial processing the camera position is available with accuracies of ±2-3 cm, while the typical angular accuracy of the sensor orientation is ±0.004° (roll and pitch) and ±0.008° (yaw) with a data rate of 200 Hz.

DIGITAL PHOTOGRAMMETRIC DATA PROCESSING

The digital photogrammetric HRSC processing system was developed for the Mars 96 mission in cooperation with the Technical University of Berlin. A completely automated procedural software system has been built up for airborne application (Figure 3). It makes use of a set of systematically preprocessed image, orientation and calibration data. In a first step the boresight offset between the INS and camera axes can be estimated in an optimization procedure using identical points derived from the different stereo channels and from overlapping image strips without the need for ground control point information. Based on the calibration data and applying the INS/camera offsets to the orientation data each image line is projected to an artificial surface which is defined by the mean elevation of the imaged region.

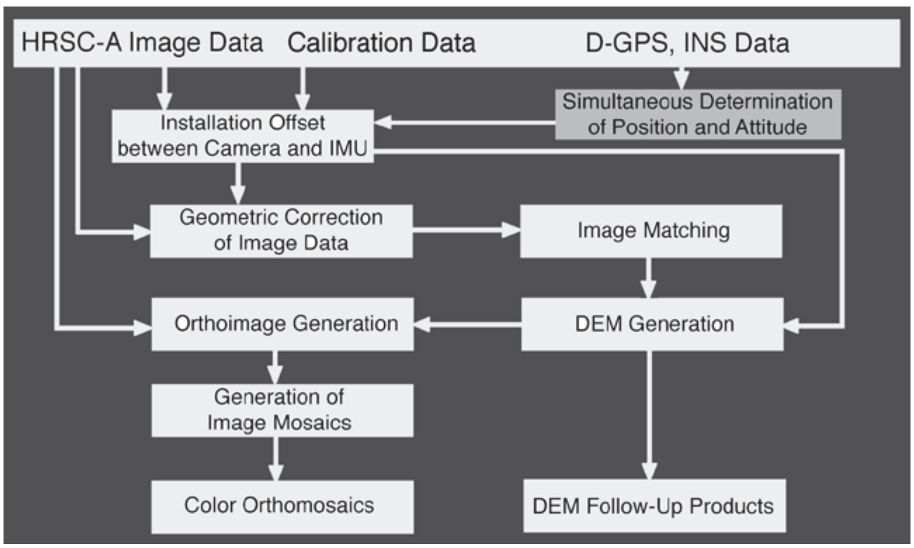

Figure 3. Photogrammetric Processing Line for HRSC-A Data

One fundamental quality of the HRSC-A is, beside its high resolution and multispectral capabilities, its multi-stereo functionality. Based on the pre-rectified image data a multi-image matching technique is applied to derive identical points in each of the five stereo channels. Due to the five different viewing angles, the complete image can be matched even in urban areas (where gaps are more likely to appear when systems providing only two stereo observations are used). Together with the calibration data and the orientation information each set of image coordinates define a bundle of rays in object space. The final object point is the intersection of these rays. A Digital Elevation Model (DEM) is now calculated from the set of object points using different interpolation techniques depending on the surface type. The DEM, now given in any requested map projection, can be used for the extraction of different 3D follow-up products. Finally, it is the basic prerequisite for the following generation of HRSC-orthoimages. The final step within the photogrammetric data processing is the generation of orthoimage mosaics using orthoimages of adjacent strips. The result is a homogeneous image mosaic for each spectral band.

POTENTIAL OF THE HRSC-A FOR CARTOGRAPHIC APPLICATIONS

Based on the digital concept of the camera and its associated digital photogrammetric processing line, the HRSC-A system enables various cartographic applications. On the one hand, different map scales can be derived with appropriate accuracy. But not only high-resolution and high-accurate data are the main advantages of the system, the multi-spectral image data can also directly be used for various thematic representations, especially combined with the 3D-capabilities of the system. Table 3 gives an overview of the ground resolution and accuracy of HRSC-A image and 3D-data and the resulting capabilities for different map scales. If high-resolution panchromatic data are merged with multi-spectral data (e.g. by using HSI-color transformation), the resulting data set includes both high resolution and multi-spectral information and can be used for nearly the same map scales as given for panchromatic data.

Flight Altitude	Ground Resolution panchrom./multispectral	Planimetric Accuracy	Height Accuracy	Appropriate Map Scales panchrom./multispectral
1500 m	0.12 m / 0.35 m	0.10 m	0.15 m	≤ 1: 500 /≤ 1: 1500
3000 m	0.15 m / 0.40 m	0.15 m	0.20 m	≤ 1: 750 / ≤ 1: 2000
6000 m	0.20 m / 0.45 m	0.30 m	0.40 m	≤ 1: 1.500 / ≤ 1: 3500

Table 3: Resolution, Accuracy, and Cartographic Capabilities of HRSC-A Image Data

The completely digital and highly automated imaging and processing line enables the unique derivation of high-resolution and multi-spectral image and 3D-data, combined with short processing periods. Project areas of several hundred square-kilometers can be processed within few weeks, yielding products such as colour orthoimage mosaics and Digital Elevation Models. Further parallized processing techniques will even reduce the production time. Thus, not only large scale applications but also mapping in medium scales (e.g. 1: 10000 to 1: 25000) can be performed.

APPLICATION EXAMPLES

Since the first airborne experiments (May 1997), the HRSC-A system has been used for many different applications. High resolution multispectral orthoimages and DEM data have been acquired for applications as different as mapping of active volcanoes, urban areas, open coal mines, flood hazards, and coastal zones. Planning requirements for urban areas increasingly involve GIS technology, e.g. using 3D models for the needs of the mobile phone service in the telecommunication industry (Renouard & Lehmann, 1999). The need for both high resolution multispectral images and DEM data can be addressed by airborne digital imaging with the HRSC-A.

GEOSCIENTIFIC AND ENVIRONMENTAL APPLICATIONS

In May 1997, a flight campaign at the Aeolian Islands (Italy) was carried out to assess the potential of HRSC-A for applications in volcanology and comparative planetology (Gwinner et al., 1999). The camera was operated from a flight altitude of 5,000 m. The corresponding ground pixel sizes are 25 cm for the nadir channel, 50 cm for the remaining panchromatic stereo and photometry channels, and 100 cm for the multispectral channels. A DEM on a 160 cm grid and a multispectral orthoimage mosaic have been derived for the entire Island of Vulcano. A topographic image map at scale 1: 5,000 (Figure 4) of the active volcano “La Fossa“ has been produced from these data acquired by a single sensor system (Gwinner et al., 2000).

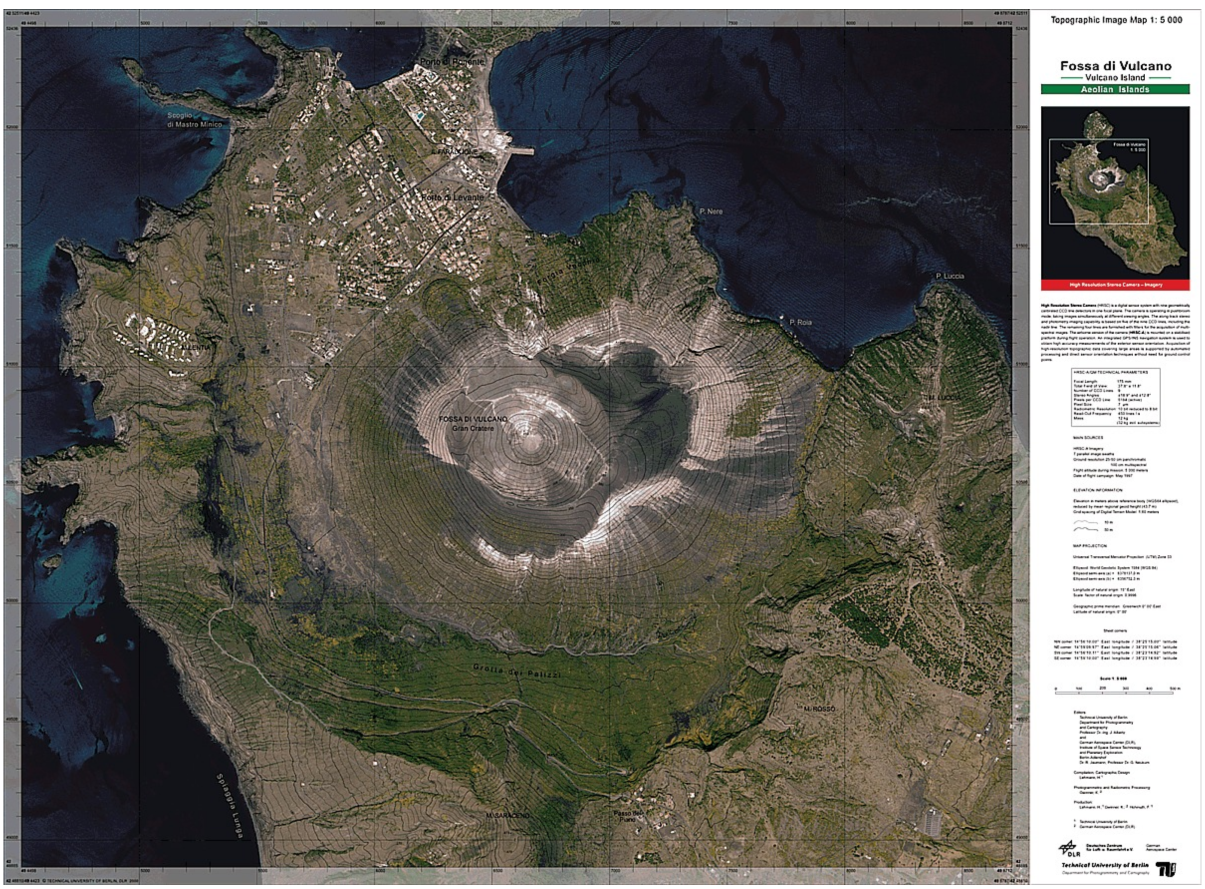

Figure 4. Topographic Image Map Fossa di Vulcano 1: 5,000. Color orthoimage mosaics, contour lines, and spot heights have all been derived from HRSC-A stereo imagery.

The flight campaign for a pilot study in glaciology (Figures 5, 6) took place in late summer 1999, when snow coverage on the glacier is at its yearly minimum This is the most convenient season for remote sensing of glaciers, since a) the volume measurements are not biased by snow coverage, and b) the glacier surface provides a maximum of texture which is important for automatic correlation of the stereo images. Within a period of 3 hours about 40 Gbyte of stereo and multispectral data were acquired on more than 20 image tracks, covering about 100 km^2. The flight altitude was 5800 m a.s.l. or 3000 m above mean ground level, yielding mean ground pixel sizes of 14 cm.

The above examples have demonstrated the high potential of the system for mapping areas with high topographic relief as well as weakly textured surfaces. Of particular value for geoscientific applications is, in addition to geometric accuracy, direct sensor orientation allowing to provide up-to-date topographic base data without any need for ground control and interactive processing.

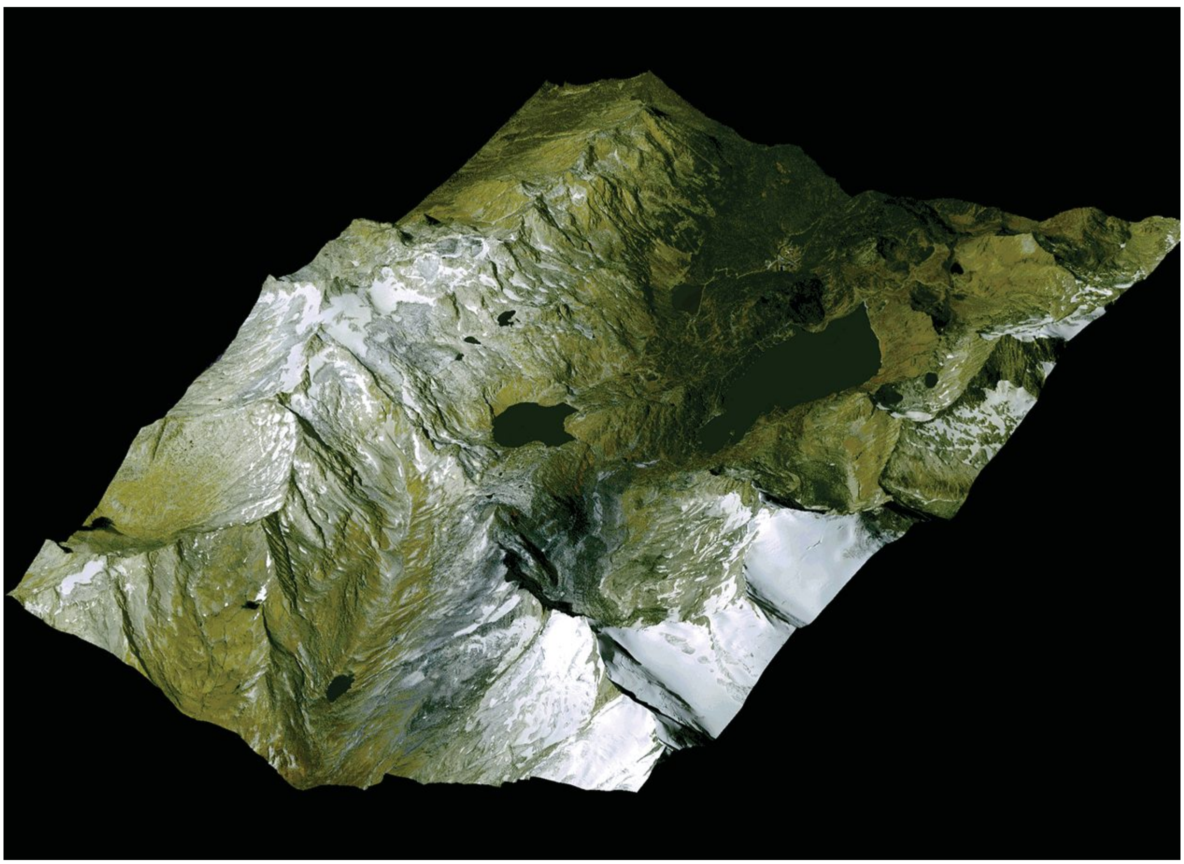

Figure 5. HRSC-A synthetic perspective view of Stubachtal (Austria) and the Sonnblickkees glacier (see Fig. 6 for detail).

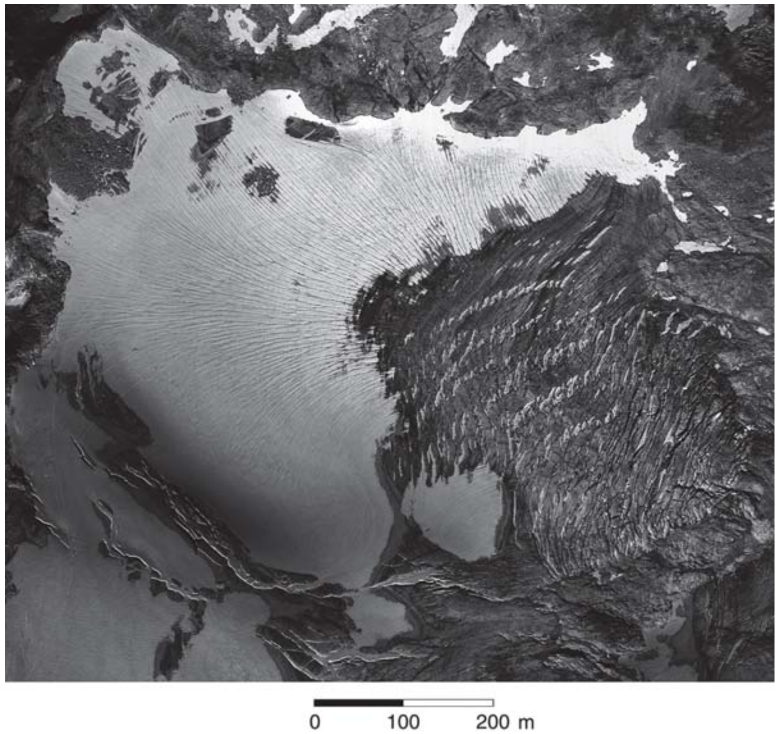

Figure 6. HRSC-A nadir orthoimage of the Sonnblickkees glacier.

MAPPING OF URBAN AREAS

The potential of the the HRSC-A system for photogrammetric surveys in urban areas has been shown in its operational use at several European cities. Specifically, the availability of five stereo observations, including the near-nadir looking photometry channels, is beneficial for the measurement of man-made objects typically including steep surface discontinuities.

The cartographic potential of the HRSC-A system for mapping urban areas was demonstrated by the generation of a true-color map sheet of the Image Map 1:5,000 series of the city of Berlin (Figure 7) in cooperation with the "Senatsverwaltung für Bauen, Wohnen und Verkehr, Berlin".

CONCLUSIONS

As a spin-off development of camera technology and photogrammetric software originally developed for planetary exploration, the HRSC-A system has demonstrated a unique potential for high-resolution digital photogrammetric mapping in various airborne terrestrial applications. The achieved accuracies show that the combination of a multi-spectral digital line scanner with a comprehensive processing system yields highly accurate data products under difficult conditions and for large regions. According to still higher image resolutions and the accuracy of the navigation data, the recently introduced camera versions will allow to extend these capabilities into the sub-decimeter range. Furthermore, the digital techniques enable new possibilities for geoscientific, environmental and cartographic applications while eliminating costs associated with film use, digitizing, interactive processing, and geodetic field-work.

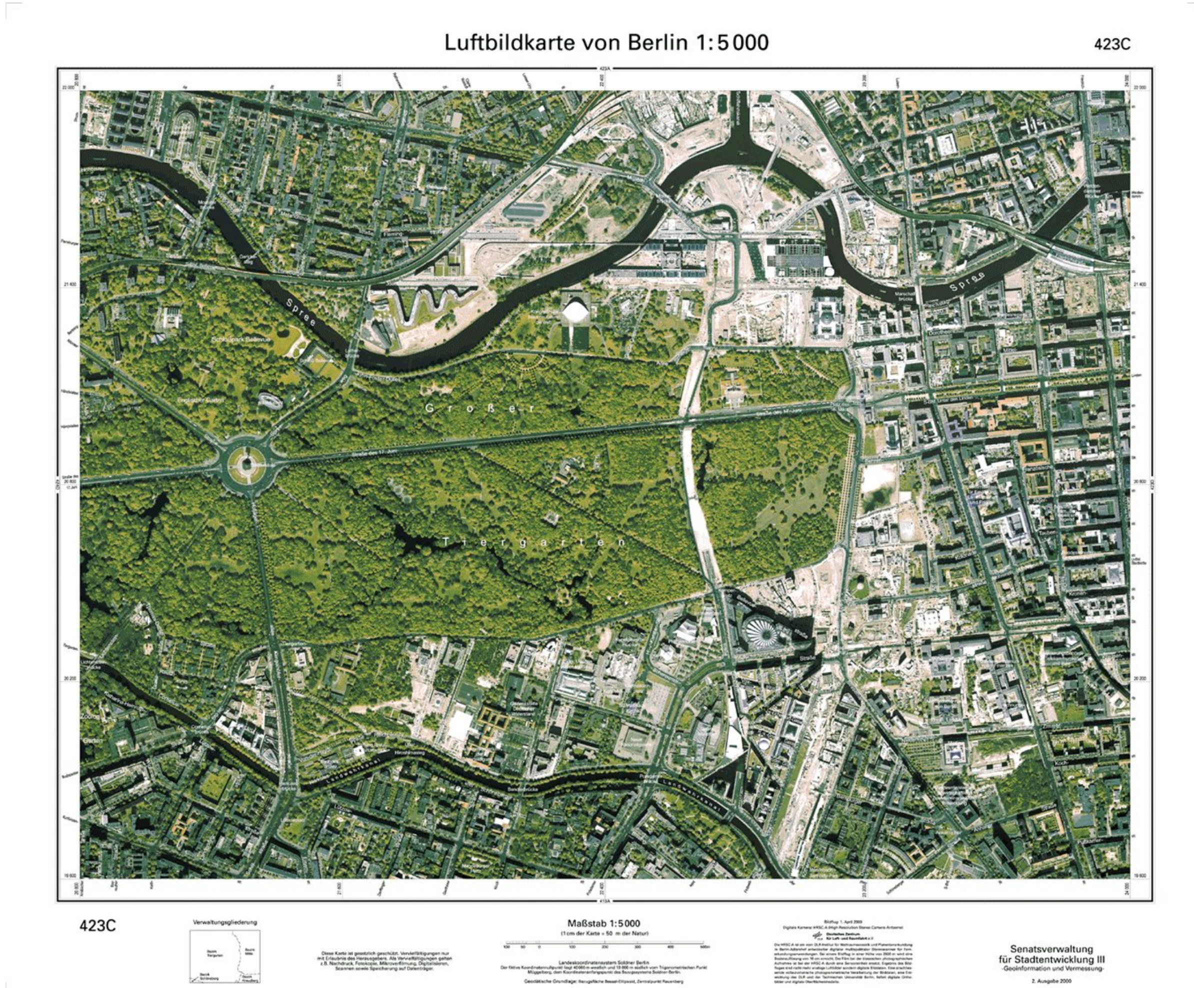

Figure 7. Orthoimage Map of Berlin-Tiergarten, 2000.

ACKNOWLEDGEMENTS

We would like to acknowledge the scientific and operational contributions of all persons of the DLR involved in the HRSC-A developments and flight campaigns. We also thank for the cooperation of Istituto Internazionale die Vulcanologia, Catania, University Salzburg, Institute of Geography and Applied Geoinformation, Technical University of Berlin, Department Photogrammetry and Cartography, and Free University Berlin, Institute of Geology, Geophysics, and Geoinformatics, which were involved in the flight campaigns.

REFERENCES

J. Albertz, F. Scholten, H. Ebner, C. Heipke, G. Neukum, "The Camera Experiments HRSC and WAOSS on the Mars94 Mission". International Archives of Photogrammetry and Remote Sensing, Vol. 29, Part B1, pp. 216-227, 1992.

K. Gwinner, H. Lehmann, J. Albertz, "The 'Topographic Image Map Fossa di Vulcano 1:5,000' – a digital mapping approach based on HRSC-A imagery", International Archives of Photogrammetry and Remote Sensing, 33, Part B4, pp. 63-69, 2000.

K. Gwinner, E. Hauber, H. Hoffmann, F. Scholten, R. Jaumann, G. Neukum, M. Coltelli, G. Puglisi, "The HRSC-A Experiment on High Resolution Imaging and DEM Generation at the Aeolian Islands". 13th Int. Conf. Applied Geologic Remote Sensing, Vancouver, Canada, Vol. I, 560-569, 1999.

G. Neukum and V. Tarnopolsky, "Planetary Mapping – The Mars Cartographic Data Base and a Cooperative Camera Project for 1994". Geo-Informationssysteme, 3, H. 2, pp. 20-29, 1990.

G. Neukum., J. Oberst, G. Schwarz, J. Flohrer, I. Sebastian, R. Jaumann, H. Hoffmann, U. Carsenty, K. Eichentopf, R. Pischel, "The Multiple Line Scanner Camera Experiment for the Russian Mars96 Mission: Status Report and Prospect for the Future". In Photogrammetric Week '95, eds. D. Fritsch & D. Hobbie, Wichmann, Heidelberg, Germany, pp. 45-61, 1995.

G. Neukum and the HRSC Co-Investigator and Experiment Team, "The High Resolution Stereo Camera (HRSC) onboard the European Mars Express Mission". ESA, 12 p., 2000 (in press).

L. Renouard, F. Lehmann, "Digital Aerial Survey Data for Telecoms Network Planning: Practical Experience with a High-Resolution Three-View Stereo Camera". OEEPE Workshop on Automation in Digital Photogrammetric Production, Paris, France, 21-24 June 1999.

F. Wewel, F. Scholten, K. Gwinner, "High Resolution Stereo Camera (HRSC) – Multispectral 3D-Data Acquisition and Photogrammetric Data Processing". Canadian Journal of Remote Sensing, Vol. 26, No. 5, pp. 466-474, 2000.