Operational Parallel Processing in Digital Photogrammetry-Strategy and Results using Different Multi-Line Cameras

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ABSTRACT:

Digital sensors, providing excellent quality with respect to geometry and radiometry, are more and more replacing traditional analogue photogrammetric data acquisition. Allowing for a completely digital data flow, particularly line scanners based on the three-line principle offer new opportunities for higher productivity and for cost reduction, since automated processing of orthoimages and DEM does not depend on specific and expensive photogrammetric hardware components. With the airborne version of the HRSC (High Resolution Stereo Camera) the efficiency of this end-to-end approach to digital photogrammetric mapping has been proven within many projects during the past 7 years. The system can be applied to data of any three-line sensor since it is based on the general camera model of a multi-line camera. Thus, besides photogrammetric data products derived from imagery of the HRSC versions HRSC-A/AX/AXW, also data of LH SYSTEMS ADS40 have been processed successfully.

1. INTRODUCTION

Building upon previous developments (Wewel et al., 2000, Scholten et al., 2000), which started in 1997 based on digital data of the HRSC-A camera, the entire system for DLR's airborne HRSC data acquisition and photogrammetric data processing has been further optimized. The airborne HRSC is a high-resolution digital photogrammetric multi-line sensor system applying the pushbroom and multi-stereo imaging principles to derive multi-stereo and multi-spectral imagery along the flight track. While the HRSC camera family was extended by the HRSC-AX and -AXW (12,000 pixel/line with 150 mm resp. 47 mm focal length) the workflow of the automated photogrammetric data processing has been entirely re-designed to allow for parallelization based on client/server processes. In contrast to traditional processing based on specific photogrammetric hardware or software solutions linked to interactive workstations this new approach is responsive to the needs for time and cost efficient processes in modern digital photogrammetry.

The intensive use of direct geo-referencing by high-end DGPS/INS systems, combined with high redundancy provided by the multiple-stereo characteristics of HRSC allows a streamlined generation of high-resolution raster products, such as true-ortho image mosaics and digital surface models (DSM) (see Figure 1).

Figure 1. HRSC-AX standard products: 1m-digital surface model, true-color and CIR ortho-image mosaic (15cm/pixel) (Berlin 2003, flight altitude 4,400m, subset Tempelhof Airport)

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Based on these geo-referenced standard products traditional data analyses within common software packages or new developments, e.g. automated extraction of object features is performed. Functionality for manual or semi-automated real-time editing of multi-line scanner data products (e.g. DSM) will probably soon be available as a part of commercial software solutions.

Since 1997, a multitude of successful airborne HRSC application projects have been carried out. After the first extensive camera experiments which had a focus on geoscience (Gwinner et al., 1999; Gwinner et al., 2000a), different applications in environmental science, civil engineering and cartography followed soon after. Some examples include topographic mapping and map-updating (Hoffmann et al., 2000; Gwinner et al., 2000b), high mountain cartography (Hauber et al., 2000), geologic mapping and natural hazards (Gwinner, 2001; Baldi et al., 2002), hydrologic (Martin & O'Kane, 2000) and ecologic investigations (Leser, 2002) as well as telecom network planning (Renouard & Lehmann, 1999) and digital city models (Möller, 2000).

2. HRSC DATA FLOW

Figure 2 shows the entire HRSC data flow from digital data acquisition of image and orientation data to ground data processing of the photogrammetric final products. In addition to data of the HRSC cameras, the processing system can handle any other multi-line scanner data, provided that the necessary specifications for data integration as well as sensor-specific calibration data are provided. For test purposes, a data set of LH SYSTEMS ADS40 has already been integrated and was processed successfully to DSM and ortho-images (see chapter 6).

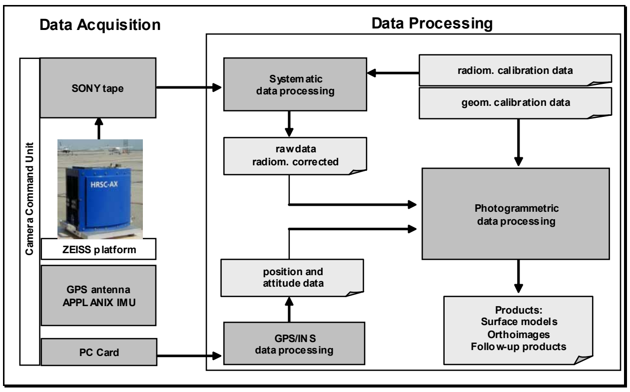

Figure 2. HRSC data flow

3. PHOTOGRAMMETRIC DATA PROCESSING LINE

All the above mentioned applications have exploited many TBytes of airborne HRSC data processed with the photogrammetric data processing system (Figure 3), which includes radiometric adjustments such as corrections for illumination effects and relative adjustment of adjacent image strips for mosaicking. The development of a high extent of automation is a precondition to handle these data volumes. No ground control information is necessary for the generation of ortho-image mosaics and DSM since the orientation data quality provided by the DGPS/INS systems adapted to the HRSC cameras is sufficiently high (Scholten et al., 2001; Scholten et al., 2003a). Camera/IMU boresight alignment or camera/orientation time line offsets are determined by means of HRSC's internal multi-stereo capability.

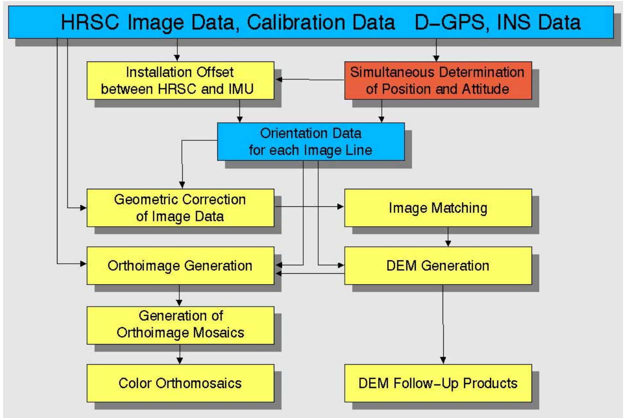

Figure 3. HRSC photogrammetric data processing

4. PARALLEL PROCESSING ON PC CLUSTER

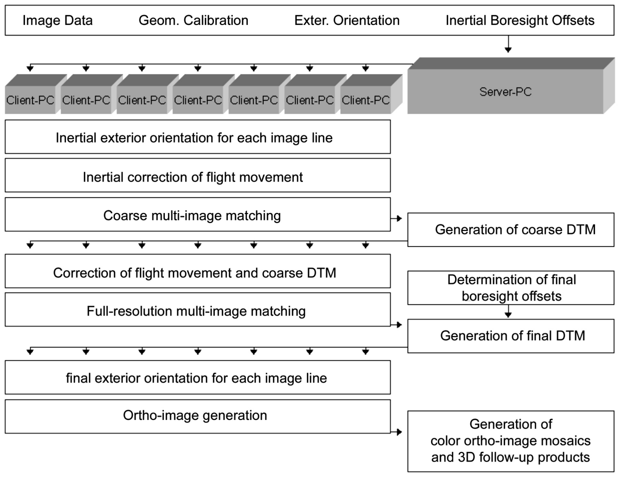

Figure 4. Parallel processing structure

The efficiency of the previously described photogrammetric processing line could be enhanced significantly by implementing parallel processing capabilities on a cluster of Linux-PCs in contrast to traditional processing of aerial images based on photogrammetric single-workstation concepts.

The DLR cluster currently consists of 24 clients and 2 servers, each of them equipped with double-CPUs. The servers perform the project management and conduct all project-wide processes (e.g. mosaicking and DSM interpolation for all image strips), while processing steps which can be performed independently for each strip are distributed to the PC-clients. Each successful step signals its completion, and thus enables the automatic initialization of subsequent steps until the final products are derived. Client processes, continuously checking for automatically requested operations, ensure that the load of the available hardware is maximized.

The mother process of a specific project is a shell script running on a server. It includes the access to the raw data, the initialization of all client processes and the final product generation. Project parameters are defined within a set-up file the content of which can be adapted to the specific project requirements, e.g. the definition of datum shift parameters to the requested geodetic datum. Client processes are also shell scripts containing the single programs for image matching, ortho-image generation etc.

5. PROCESSING SYSTEM EFFICIENCY

Table 1 gives an impression of the net processing time for an exemplary HRSC-AX project with the following parameters (loading a 50 CPU-cluster to approx. 50%):

Project size:	500 km^2 (20 km x 25 km)
Flight altitude:	4,000 m above ground
Ground resolution:	17 cm/pixel
Swath width:	1,800 m
Side lap:	50 %
No. flight strips:	20
Strip length:	25 km

A product set consisting of 20cm/pixel ortho-image mosaics in true-color, color-infrared, black/white, and black/white infrared, as well as 1m-gridded DSM is assumed.

Generation of coarse DSM (5 m-grid)	within 1 day
Generation of final DSM (1 m-grid)	4 - 7 days
Generation of all ortho-image mosaics (20cm / pixel)	2 - 3 days

Table 1. HRSC Processing efficiency

Thus, even including common time add-ons (for data handling, controls, data transfer, tiling, etc.), project areas of hundreds of square kilometers can be processed at high resolution within few weeks. Note also that, due to parallel processing, the number of image strips of a project has only a secondary effect on the overall processing time (as long as enough clients are available). Only project-wide processing steps (such as mosaicking, DSM generation) are directly extended.

6. SYSTEM ACCURACY, ROBUSTNESS, AND COMPATIBILITY

Within most HRSC projects, investigations of the accuracy of the data processing and products confirmed the high quality of all data used for direct geo-referencing (interior and exterior orientation, measurement/matching of image coordinates). From flight altitudes of 3,000-4,000m, the relative accuracy for forward ray intersection of up to 5 stereo observations within an image strip was found to be 10-15 cm for selected points measured manually, and 15-20 cm for area-based image matching results. Strip-to-strip discrepancies typically range from 15 to 20 cm. The overall mean absolute point accuracy is about 15-25 cm (3D RMS, 1 sigma). Compared to these values the point accuracy at steep edges (e.g. buildings, bridges, etc.) is decreased when these discontinuous objects can not be modelled with sufficient accuracy by stereo observations because of dissimilarity of the stereo image data.

Figure 5. Robustness of geometric correction (left: raw data, right: rectified data)

The robustness of the processing system is clearly illustrated by an extreme data set (Figure 5), acquired when the stabilized platform, to which HRSC was mounted to, bumped during flight because of an excessive stalling angle of the aircraft. The frequency of this effect of a few Hz causes abnormal distortions (far away from the nominal case) in the raw image data. Nevertheless, the permanent and precise high-frequency data provided by the inertial measurement unit enabled a nearly perfect reconstruction of the scene automatically without any operator interaction.

Figure 6. Subsets of ortho-images and digital surface models derived by DLR's processing system for multi-line scanners

top: HRSC-AX, Potsdam, Germany, flight altitude 4,000m, ground resolution 17 cm

bottom: ADS40, Nimes, France, flight altitude 800m, ground resolution 8 cm

The processing system is able to handle data of all different HRSC camera types (HRSC-A/AX/AXW) and, provided adequate interior orientation data is available, of other sensors based on the multi-line principle. Figure 6 shows an example of ortho-images and DSM from ADS40 data (raw data kindly provided by LH SYSTEMS) and of an HRSC-AX data set.

The data of both sensors have been processed with the one and the same software system, which has been described above. Note that the parameters and target areas of both flights were different, thus the data cannot be compared directly.

7. FURTHER EXTENSION OF THE PROCESSING LINE

Figure 7. DSM Improvement of building shapes
(Berlin, 2001, flight altitude 5,000m, subset Adlershof)
top: perspective view using automatically derived HRSC DSM
bottom: perspective view using vector enhanced DSM

Subsequent to the photogrammetric processing line, many applications based on precise 3D and orthoimage data may follow. Current developments are addressing also the automatization of frequently required related tasks such as the extraction of buildings in urban areas and data preparation for high-sophisticated visualization and animation processes. Examples are the integration of exterior vector information into the photogrammetric process in order to optimize the product charactristics for visualization (Figure 7; Scholten et. al, 2003b) and the automated enhancement/extraction of linear features, such as 3D building shapes, in combined ortho-image and DSM data sets (Mayer, 2004).

CONCLUSIONS

Airborne HRSC system operations and photogrammetric data processing has proven its feasibility with many applications. It has demonstrated that the demands on efficient data processing can be satisfied by means of automated processes combined with robust and accurate processing based on the multi-stereo capability owned by multi-line scanners.

Parallel processing on large PC-clusters has been introduced as a feasible concept that enables handling of very large data sets and optimal utilization of hardware capacities. It can be a basis for more commercial applications in the near future. Nevertheless, there is still a need for additional tools to extend the product line (e.g. the extraction of linear features and derivation of 3D object shapes).

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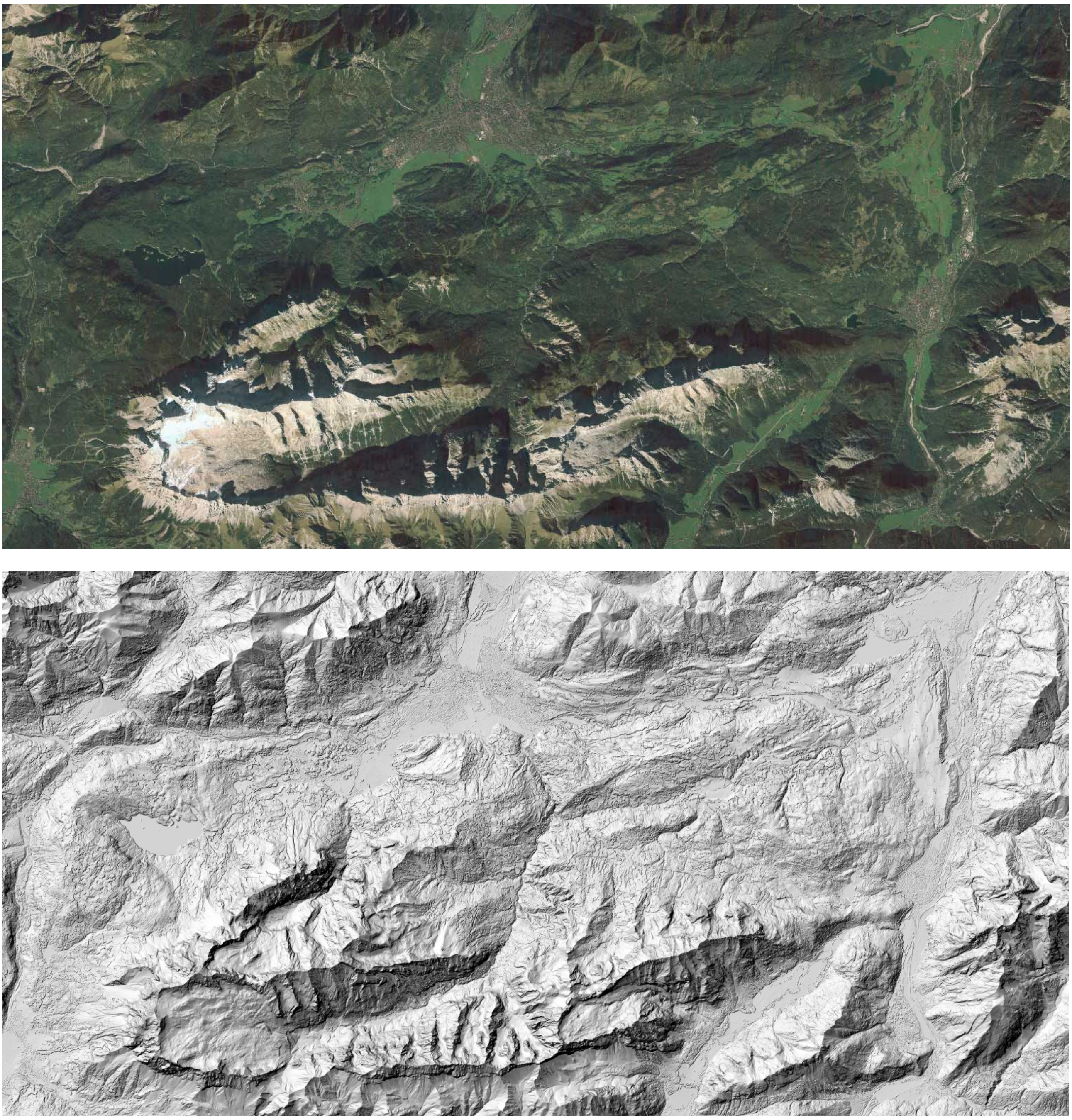

Figure 8. HRSC-AX ortho-image mosaic (15 cm/pixel) and DEM, shaded relief, (1m-grid) "Zugspitze" (Germany's highest mountain) and its vicinity (subset of approx. 500 km^2), Bavarian Alps.

REFERENCES

P. Baldi, S. Bonvalot, P. Briole, M. Coltelli, K. Gwinner, M. Marsella, G. Puglisi, D. Rémy, 2002. Validation and Comparison of Different Techniques for the Derivation of Digital Elevation Models and Volcanic Monitoring (Vulcano Island, Italy). *International Journal of Remote Sensing,* Vol. 23 (22), pp. 4783-4800.

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

Gwinner, K., Hauber, E., Jaumann, R. & Neukum, G., 2000a. High-resolution, digital photogrammetric mapping: a tool for Earth science. Eos, 81 (44), pp. 513-520.

Gwinner, K., Lehmann, H., Albertz, J., 2000b. The Topographic Image Map Fossa di Vulcano 1: 5000 – A Digital Mapping Approach based on High Resolution Stereo Camera-Airborne Imagery. *International Archives of Photogrammetry and Remote Sensing* 33 (B4), pp. 63-69.

Gwinner, K., 2001: Anwendungspotential hochauflösender digitaler Stereobilder als topographische Datengrundlage – Fallstudie zur Geologie von Vulcano. Publikationen der Deutschen Gesellschaft für Photogrammetrie und Fernerkundung, Vol. 9, pp. 302-311.

Hauber, E., Jaumann, R., Wewel, F., Gwinner, K., Neukum, G., Slupetzky, H., 2000. The Airborne High Resolution Stereo Camera (HRSC-A) as a Tool for High Mountain Cartography. - Kartographische Bausteine 18, pp. 29-38, Dresden, Germany.

Hoffmann, A., van der Vegt, J.W., Lehmann, F., 2000. Towards automated map updating: is it feasible with new digital data acquisition and processing techniques?. *International Archives of Photogrammetry and Remote Sensing*, XXXIII, Part B4, pp. 63-69, Amsterdam, Netherlands.

Leser, C., 2002: Operationelle Biotoptypenkartierung mit HRSC-Daten – Probleme und Lösungsansätze. In: Blaschke, Fernerkundung und GIS, pp. 88-97, Heidelberg, Germany

Martin, J. & O'Kane, J.P., 2000. Integration of physically based computer models with high resolution digital elevation models for the generation of flood maps. – Water in the Celtic World: Managing Resources for the 21st Century, British Hydrological Society, pp. 181-188.

Mayer, S., 2003. Automatisierte Objekterkennung zur Interpretation hochauflösender Bilddaten in der Erdfernerkundung. Ph.D. Thesis, Naturwissenschaftliche Fakultät II, Humboldt University, Berlin, Germany. http://edoc.hu-berlin.de/

Möller, M., 2000. Applications of very high resolution digital airborne scanner data. *International Archives of Photogrammetry and Remote Sensing*, XXXIII, Part B4, pp. 663-669, Amsterdam, Netherlands.

Renouard, L. & Lehmann, F., 1999. High resolution digital surface models and orthoimages for telecom network planning. In: Fritsch & Spiller, Photogrammetric Week ´99, pp. 241-246, Heidelberg, Germany.

Scholten, F., Wewel, F., 2000. Digital 3D-data Acquisition with the High Resolution Stereo Camera Airborne (HRSC-A). *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, Part B4, pp. 901-908, Amsterdam, Netherlands.

Scholten, F., Wewel, F., Sujew, S., 2001. High Resolution Stereo Camera - Airborne (HRSC-A): 4 Years of Experience in Direct Sensor Orientation of a Multi-Line Pushbroom Scanner. In: International Society for Photogrammetry and Remote Sensing, Proceedings of Joint Workshop "Sensors and Mapping from Space 2001", Veröffentlichungen des Instituts für Photogrammetrie und Geoinformation, University of Hannover, Germany.

Scholten, F., Sujew, S., Gwinner, K., 2003a. Application of GPS/INS-Systems with the HRSC - A Comparison of Applanix POS/AV-510 and IGI AEROcontrol-IId. Proceedings of ISPRS Workshop WG I/5 Workshop "Theory, Technology and Realities of Inertial/GPS Sensor Orientation", Castelldefels, Spain.

Scholten, F., Gwinner, K., Tauch, R., Boulgakova, O., 2003b. HRSC-AX - High Resolution Orthoimages and Digital Surface Models for Urban Regions. Proceedings of 2nd GRSS/ISPRS Joint Workshop "Remote Sensing and data Fusion over Urban Areas", pp. 225-229, Berlin, Germany.

Wewel, F., Scholten, F., Gwinner, K., 2000. High Resolution Stereo Camera (HRSC) – Multispectral 3D-Data Acquisition and Photogrammetric Data Processing. *Canadian Journal of Remote Sensing,* 26 (5), pp. 466-474.