EUROPEAN GROUND SEGMENT FOR HIGH RESOLUTION IKONOS DATA

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ABSTRACT:

A new European receiving station for high resolution IKONOS data is operated at Oberpfaffenhofen near Munich, Germany, since April 2003. The station is running under collaboration between European Space Imaging and the German Aerospace Center DLR. With a reception cone that covers Europe and North Africa, it enables European users to have direct and fast access to IKONOS data. Due to the new receiving station DLR extends its acquisition capabilities and has now real-time access to a variety of Earth observation sensors with spatial resolutions ranging from 1 km to 1 m.

The paper gives an overview on the present status of the European IKONOS ground station at DLR. The image reception, data processing, archiving, and product delivery are explained. Moreover, the operational capacity and throughput of the ground station as well as the quality of the products are shown. Finally, an outlook on further expansion and improvements of the station as well as future research and development activities with respect to information extraction from IKONOS imagery is given.

1 INTRODUCTION

Launched in September 1999, the IKONOS Earth observation satellite system, with 1-meter panchromatic and 4-meter multi-spectral resolution, provides significant new means for geo-spatial information collection for a wide variety of applications. Together with the recently available high resolution sensors on the satellites QuickBird (Digital Globe), EROS-A1 (ImageSat), and SPOT-5 (Spot Image) a enormous potential of Earth observation imaging capacity currently exists.

Research activities have been mainly focussing on the radiometric and geometric accuracy aspects in ortho-image generation and DEM extraction (e.g. Davis, Wang, 2001; Jacobsen, 2001; Toutin, 2003). Recently, research work is increasingly concentrating on automatic feature detection, recognition and reconstruction. Significant progress has been achieved e.g. in the automatic mapping of roads (e.g. Dial et al., 2001; Hofmann, 2001; Brussel et al., 2003; Gibson, 2003) and in 3D building extraction (e.g. Fraser et al., 2002; Lee et al., 2003).

Moreover, besides research and development, there is high demand for operational ground segment capabilities for data acquisition, processing, archiving and product delivery in order to provide the technical infrastructure for the full exploitation of the scientific and commercial potential of this data source.

Since April 2003, a new European receiving station for IKONOS data is operated at Oberpfaffenhofen near Munich, Germany. The station is running under collaboration between the German Aerospace Center DLR and the company European Space Imaging. The reception cone of the station, that covers Europe and North Africa, enables European users to have direct and fast access to IKONOS data.

The paper gives an overview on the present status of the European IKONOS ground station at DLR. Image reception, data processing, archiving, and product delivery are explained. Moreover, the operational capacity and throughput of the ground station as well as the quality of the products are shown. Finally, an outlook on further expansion of the station as well as future research and development activities is given.

2 IKONOS SATELLITE AND SENSOR

IKONOS is operated in a near-polar orbit with a sun-synchronous 98-degree inclination at an altitude of 680 km and an orbital period of 98 minutes. The descending crossing time is at about 10:30 local time.

The satellite attitude is determined by on-board star trackers and gyroscopes; the low frequency star tracker data and the high frequency gyroscope data are combined based on a Kalman filter post-processing approach. Interlock angles relate the satellite attitude to the camera orientation angles.

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The satellite ephemeris and the camera position for each image line is derived from on-board GPS data, which are post-processed using orbital models.

IKONOS is a fully agile satellite. Unlike e.g. Landsat, which only images at nadir, and SPOT, which has a rotating mirror permitting side-to-side image acquisition, IKONOS can be rotated to acquire images on both sides as well as forward or backward of the ground track.

The spatial resolution (ground sampling distance) at nadir is 0.82 m at for panchromatic images and 3.28 m for multi-spectral images. At 30 degrees off-nadir the spatial resolution is 1 m and 4 m, respectively. The swath width is 11.3 km at nadir and about 13.8 km at 26 degrees off-nadir.

The nominal repeat cycle is 140 days. Due to the off-nadir pointing abilities the revisit time is 3 days at 1 m spatial resolution and 1.5 days at 1.5 m resolution (at 40 degrees latitude). The multi-spectral bands are in the visible (blue: 0.45–0.52 µm, green: 0.52–0.60 µm, red: 0.63–0.69 µm) and near-infrared (0.76–0.90 µm) part of the spectrum; the pan-chromatic band ranges from 0.45 – 0.90 µm. The radiometric resolution is 11 bits for all bands. Radiometric calibration can be done on the basis of calibration coefficients (Space Imaging, 2001; Bowen, 2002).

3 IKONOS INTERNATIONAL GROUND SEGMENT

The IKONOS ground segment consists of the Primary Operations Center (POC) and several Regional Operations Centers (ROCs) world-wide. The Primary Operations Center is located in Thornton, Colorado, USA; three additional remote terminals are in Alaska, Oklahoma and Kiruna.

The Regional Operations Centers are operated by international affiliates, which have the ability to autonomous-ly task the satellite within their communication cone. Currently, these regional affiliates are Space Imaging Asia, Japan Space Imaging, Space Imaging Southeast Asia, Space Imaging Middle East, Space Imaging Eurasia, and since 2003 European Space Imaging (Fig. 1).

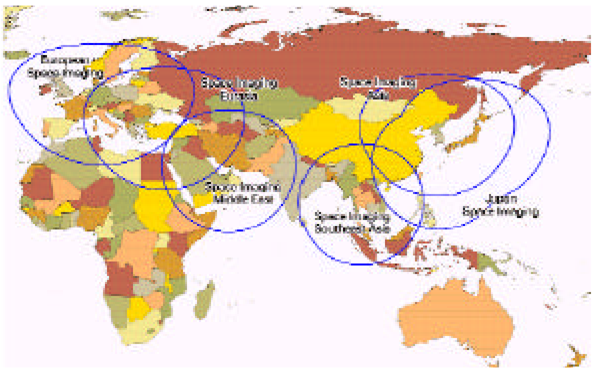

Figure 1: Global Network of IKONOS Regional Operations Centers (from: Space Imaging, 2003)

4 EUROPEAN GROUND STATION

Under co-operation between DLR and European Space Imaging, DLR's German Remote Sensing Data Center (DFD) operates a IKONOS receiving station as Regional Operations Center in Europe. The ground station is located in Oberpfaffenhofen near Munich. The reception cone of the station covers Europe and North Africa and thus enables European users to have direct and fast access to IKONOS data (Figure 2).

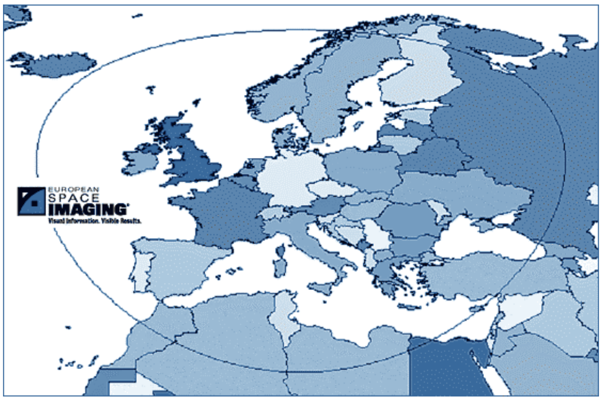

Figure 2: Reception cone of the European IKONOS Ground Station at DLR

4.1 Image acquisition

Image acquisition is performed on customers demand. It involves the following steps.

4.1.1 Product Ordering

Customers can either purchase imagery, which is already available in the archive, or they can order new data collections, which require scheduling and tasking of the IKONOS satellite. This is done according to a standard ordering form, in which the product level, collection requirements, time frame etc. are specified.

The product order is received by the customer service and a feasibility control is performed, where the order's probability of collecting in the time frame (geometric feasibility and satellite resources) is checked. If this is passed, a product order is submitted.

4.1.2 Scheduling and Satellite Tasking

24 hours before the overpass of the satellite, the scheduling is done. The geometrically feasible imaging targets are picked up and an "optimal" path is calculated. This image collection path is based on priority values (collection priority, due date, remaining collection opportunities and weather forecast) and satellite constraints.

This schedule can be modified and edited by the system operator. These edits can be made up to 7 minutes before the pass. Based on the final image collection plan the tasking commands are generated.

The tasking commands are sent to the satellite within 25 seconds of making contact to the satellite via the narrow band signal. The on-board software calculates the satellite manoeuvres, which are necessary for image collection. Telemetry confirming the successful receipt of the tasking commands is sent to the ground station via the narrow band signal.

4.1.3 Data Downlink

The image data are transmitted in real-time to the ground station via the X-band antenna. After all imagery of the pass has been received at the ground station, the metadata for the collected imagery is transmitted.

4.1.4 Metadata and Browse Generation

The received X-band data are decrypted and the corresponding image data and metadata are reassembled and processed. The as-collected satellite support data are replaced by precision ephemeris and attitude (if available) to increase product accuracy. Browse images are generated to evaluate cloud cover and to determine if the imagery fulfils the requirements.

4.2 Data Processing and Image Products

Image data are processed to six levels of products, which are determined by the level of accuracy. The location accuracy is defined by a circular error at 90% confidence (CE 90). For the stereo products the vertical accuracy is defined by a linear error (LE 90). The main product characteristics are summarised in Tab. 1 and 2 (Space Imaging, 2003).

Product Type	Positional Accuracy (CE 90)	Ortho cor-rected	Ground control points
Geo	15 m +(*)	No	No
Standard Ortho	50.0 m	Yes	No
Reference	25.4 m	Yes	No
Pro	10.2 m	Yes	No
Precision	4.1 m	Yes	Yes
Precision Plus	2.0 m	Yes	Yes
(*) plus terrain displacement			

Table 1: Georectified and Orthorectified Products

Stereo Product	Positional Accuracy (CE 90)	Vertical Accuracy (LE 90)
Reference	25 m	22 m
Precision	4 m	5 m

Table 2: Stereo Products

For further photogrammetric processing the so-called Geo Ortho Kit images, a subset of the Geo product line, are provided, which include information about the camera geometry. Moreover, also the stereo imagery pairs are provided with information on the camera model. Applying this information, the users can produce their own highly accurate orthorectified products by using commercial off-the-shelf software, digital elevation models and ground control points.

The camera model can be expressed as a generic push-broom model on the basis of modified collinearity equations, in which the orientation parameters of each image line are formulated as function of time (e.g. Mikhail et al., 2001). To simplify and standardise the distribution of the information on the camera model, the so-called Rational Polynomial Camera (RPC) Model is used (Tao, Hu, 2001).

The geometric relationship between 3D ground coordinates and 2D image coordinates is provided by the RPC model equations (OGC, 1999):

$$r = \frac{R_1(X,Y,Z)}{R_2(X,Y,Z)} \qquad c = \frac{R_3(X,Y,Z)}{R_4(X,Y,Z)} \tag{1}$$

where r and c are the normalized (offset and scaled) row and column image coordinates, X, Y, Z are normalized coordinates in object space, and R_i are polynomials with rational function coefficients (RFC). Typically, the order of the polynomials R_i is three, thus leading to 80 RFC's per image. It has been shown that there are no discernible differences between the products generated with a rigorous physical camera model and the RPC approach (Grodecki, Dial, 2001).

4.3 Archiving and Delivery

The quality of the products is reviewed and controlled, before they are delivered to the customers. All images are then stored in the archive. This is not only done for images, which are generated on the basis of customer orders, but also for so-called "speculative collections". These acquisitions are made in order to optimise the collection rate per satellite pass and are located in areas, which are likely to be requested for future revenue products.

4.4 Operational aspects

The acquisition and processing capacities of the ground station have been configured with respect to the available satellite resources and expected customer demands.

The ground station configuration is capable of handling 150 minutes IKONOS access time per month, which is expected to satisfy customer demands through the end of 2003. If required the system can quite easily be upgraded to a maximum capacity of 300 minutes of satellite access time per month.

Although IKONOS passes over the reception cone twice per day, not all passes are selected for image collection due to cloud cover prediction and the amount of orders. Pass duration varies from 4 to 10 minutes while collection yield ranges from 4 equivalent images per minute in ‘single shot’ mode to more than 30 images in the highly efficient continuous stripping mode.

With the current hardware and software configuration the first Geo level product is ready for use in approximately 20 minutes after acquisition and subsequent images are produced in 3 minute intervals. This production rate ensures that the maximum daily collection yield can be turned into actual Geo products within half a day. Ortho products take longer to produce, mainly depending on whether GCPs are required. Due to the fast production turnaround Geo level products are generally delivered within 24 hours after successful acquisition in case of FTP delivery and 2-3 days when CDs or DVDs are shipped by courier service to customers within Europe.

The current archive is based on IBM 3590 media running on a storage system with 160 media which gives a total of 1600 GByte capacity. If this archive is exceeded, the cassettes will be stored in an off-line archive. In future the IKONOS production chain will be interfaced to the DLR robot archiving system at DFD and integrated in its data and information management system (e.g. Mikusch et al., 2000). Currently, the entire IKONOS archive that Space Imaging Middle East collected since early 2000 is being loaded into the archive system of the ground station in Oberpfaffenhofen for quick delivery of Middle East products to customers in Europe.

4.5 Benefits for European users

The main advantages of an IKONOS ground station for users in Europe lie in the direct local tasking of the satellite and quick delivery. Last minute cloud cover data can be taken into account to improve collection yield significantly and shifting local acquisition priorities can be quickly implemented without having to consult the satellite operator. Recent examples of last minute tasking modifications in emergency situations were acquisitions made after the earthquake in North Algeria late May 2003 and during forest fires in Portugal in August 2003.

Future co-operation between DLR and European Space Imaging will focus on the following issues: development of an image catalogue and browse system, interactive on-line selection and ordering routines using the DLR robot archiving system, and additional remotely controlled receiving antennas in Africa. Moreover, to stimulate scientific research on the development of methods for automatic image interpretation and the exploitation of new application fields, European Space Imaging and DLR are planning to promote research activities in these fields.

5 SUMMARY AND OUTLOOK

A variety of very high resolution satellite sensors are currently providing an enormous potential for new application fields of Earth observation. The necessary basis for the exploitation of the full scientific and commercial potential is the implementation of operational ground segment infrastructure for data acquisition, processing, archiving and product delivery.

The European IKONOS ground station, which is operated in collaboration between DLR and European Space Imaging, provides an operational ground segment with direct access to IKONOS data and high-quality product generation. The reception cone of the station covers complete Europe and enables users to have direct and fast access to IKONOS data.

Image acquisition and data processing is highly operational. Two IKONOS passes per day can in principle be selected for image acquisition. The current ground station configuration is capable of handling 150 minutes IKONOS access time per month, which can be easily upgraded to a capacity of 300 minutes. The first Geo product is available at about 20 minutes after acquisition. The delivery of Geo products is generally done within 24 hours in case of FTP delivery and 2-3 days in case of CD/DVD shipment respectively.

Moreover, to stimulate scientific research and the development of methods for automatic feature extraction as well as the innovative use of these data in new application fields, European Space Imaging and DLR are planning to promote research activities or pilot applications. Details on this activity will be elaborated and announced in the near future.

REFERENCES

Bowen, H.S. (2002): Absolute radiometric calibration of the IKONOS sensor using radiometrically characterized stellar sources. Proceedings of ISPRS Commission I Symposium, 10-15 November 2002, Denver, USA.

Brussel, M., Belal, W., Rahman, M. (2003): Extracting urban road information from IKONOS high-resolution imagery. In: Jürgens, C. (Ed.): Remote Sensing of Urban Areas. Proceedings of ISPRS Workshop, 27-29 June 2003, Regensburg, Germany.

Davis, C.H., Wang, W. (2001): Planimetric accuracy of IKONOS 1-m panchromatic image products. Proceedings of ASPRS Annual Conference, 23-27 April 2001, St. Louis, USA.

Dial, G., Gibson, L., Poulsen, R. (2001): IKONOS satellite imagery and its use in automated road extraction. In: Automated Extraction of Man-Made Objects from Aerial and Space Images (III). Balkema Publishers, Lisse, 349-358.

Dial, G., Grodecki, J. (2002): IKONOS accuracy without ground control. Proceedings of ISPRS Commission I Symposium, 10-15 November 2002, Denver, USA.

Dial, G., Grodecki, J. (2003): IKONOS stereo accuracy without ground control. Proceedings of ASPRS Annual Conference, 5-9 May 2003, Anchorage, USA.

Fraser, C.S., Baltsavias, E., Gruen, A. (2002): Processing of IKONOS imagery for submetre 3D postioning and building extraction. ISPRS Journal of Photogrammetry & Remote Sensing, 56, 177-194.

Gibson, L. (2003): Finding road networks in IKONOS satellite imagery. Proceedings of ASPRS Annual Conference, 5-9 May 2003, Anchorage, USA.

Grodecki, J., Dial, G. (2001): IKONOS geometric accuracy. Proceedings of ISPRS Workshop "High Resoution Mapping from Space 2001, 19-21 September 2001, Hannover, Germany.

Hofmann, P. (2001): Detecting buildings and roads from IKONOS data using additional elevation information. GIS (6), 28-33.

Jacobsen, K. (2001): Automatic matching and generation of ortho-photos from airborne and spaceborne line scanner images. Proceedings of ISPRS Workshop "High Resolution Mapping from Space 2001", 19-21 September 2001, Hannover, Germany.

Lee, D.S., Shan, J., Bethel, J.S. (2003): Class-guided building extraction from Ikonos imagery. Photogrammetric Engineering & Remote Sensing, Vol. 69 (2), 143-150.

Mikhail, E.M., Bethel, J.S., McGlone, J.C. (2001): Introduction to modern photogrammetry, J. Wiley, New York.

Mikusch, E., Diedrich, E., Göhmann, M., Kiemle, S., Reck, C., Reißig, R., Schmidt, K., Wildegger, W., Wolfmüller, M. (2000): Data and information management system for the production, archiving and distribution of Earth observation products. Data Systems in Aerospace 2000, ESA Publications Division, SP-457, Noordwijk.

OGC (1999): The OpenGIS abstract specification. Vol. 7: The Earth imagery case. http://www. opengis.org/techno/ abstract/99-107.pdf (accessed 4 Aug. 2003).

Space Imaging (2001): IKONOS relative spectral response and radiometric calibration coefficients. Space Imaging Document. http://www. spaceimaging.com/products/ikonos/ spectral.htm (accessed 4 Aug. 2003).

Space Imaging (2003): IKONOS – Imagery Products and Product Guide.

Tao, C.V, Hu, Y. (2001): 3D reconstruction algorithms with the rational function model and their applications for IKONOS stereo imagery. Proceedings of ISPRS Workshop "High Resolution Mapping from Space 2001", 19-21 September 2001, Hannover, Germany.

Toutin, T. (2003): Error tracking in IKONOS geometric processing using a 3D parametric model. Photogrammetric Engineering & Remote Sensing, Vol. 69 (1), 43-51.