PFG 2010 / 6, 429 – 438
Stuttgart, Dezember 2010

Article

Optimised Near-Real Time Data Acquisition and Pre-processing of Satellite Data for Disaster Related Rapid Mapping

Danielle Hoja, Maximilian Schwinger, Anna Wendleder, Oberpfaffenhofen; Peter Löwe, Harald Konstanski, Horst Weichelt, Brandenburg an der Havel & Nadine Kiefl, Jürgen Janoth, Friedrichshafen

Keywords: RapidEye, Infoterra, TerraSAR-X, DLR, Rapid Imaging, Rapid Mapping, Rapid Ordering Process

Summary: In its first part this paper describes exemplarily optimisations of the satellite systems RapidEye and TerraSAR-X. For this purpose a short insight into processes, relevant for data production, will be given. Focus of this will be time constraints typical for disaster related rapid mapping.

Optimisations of geometric pre-processing of satellite data are described in a second part of this paper. For this purpose different software packages available for radar and optical data were compared and analysed respectively. Results were as far as possible optimised.

Zusammenfassung: *Optimierte Nahe-Echtzeit Akquisition und Vorverarbeitung von Satellitendaten zum Zweck der Krisenkartierung.* Dieser Artikel beschreibt im ersten Teil exemplarisch die Optimierung der Satellitensysteme RapidEye und TerraSAR-X. Hierzu wird ein kurzer Einblick in die zur Datenlieferung notwendigen Abläufe bei den Satellitendatenanbietern gegeben. Der Fokus liegt auf den zeitlichen Ansprüchen der schnellen Krisenkartierung. Die Optimierung der Vorverarbeitung der vom Satellitendatenanbieter erzeugten Daten mit dem Schwerpunkt geometrische Entzerrung wird im zweiten Teil des Artikels beschrieben. Hierzu wurden auf dem Markt verfügbare Programme für Radar- und optische Bilder jeweils verglichen, analysiert und soweit möglich Ergebnisse optimiert.

1 Introduction

During a typical disaster-related rapid mapping process several requirements have to be fulfilled by a satellite data provider. As an example, Fig. 1 shows communication and actions during a rapid mapping process between a satellite data provider and the ZKI (Centre for Satellite Based Crisis Information). It does not include actions performed within an entity.

Within the blue highlighted area the following actions are performed:

- The customer, in this case ZKI, communicates an order to the satellite data provider.
- The satellite data provider decides if the order can be answered with catalogued data or if new data has to be acquired.
  - If catalogue data is needed, the data can be served without further actions.
  - If data has to be acquired, the satellite data provider has to
    - Create a schedule for the satellite which includes the ordered data;
    - Command the satellite(s);
    - Satellite(s) acquire(s) the data;
    - Data is down linked to a ground station;
    - Data is transferred to satellite data providers catalogue.

© 2010 E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany www.schweizerbart.de
DOI: 10.1127/1432-8364/2010/0065 1432-8364/10/0065 $ 2.50

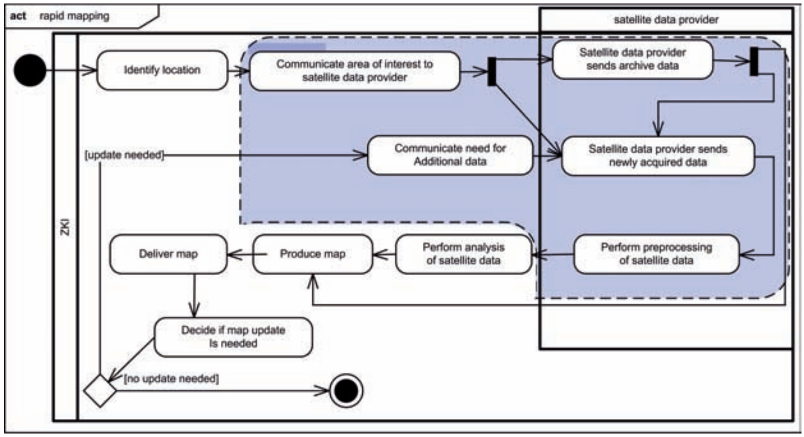

Fig. 1: Rapid Mapping Process as activity diagram. The blue highlighted area describes content which is discussed in this article.

- Data is pre-processed and delivered to the customer.

A rapid mapping process is differentiated from a normal mapping process mainly by its time constraints. To deliver information about a disaster in near real time (NRT) is vital to save lives of people involved. Near real time means the whole process only takes the time needed for processing and transfer. For satellite application this includes the time constraint arising from the satellites visibility by a ground station, which is limited by the number of used ground stations and the satellites orbit. Only if a satellite is visible to a ground station it can be commanded and data can be down linked from the satellite.

2 Typical Rapid Mapping Products

To find the right focus, typical products have to be identified and requirements which lead to this product to be devised.

After a disaster comes into focus a first product need is a **reference map**. Requirements for this map which are of importance within our focus are scale (1 : 200 000 to 1 : 25 000) and availability (worldwide within 6 hours), also the maps have to include a timestamp and geo-reference. In Fig. 2 the steps needed for creation of a reference map are depicted. The map has to be created from pre-damage data acquired prior to the disaster.

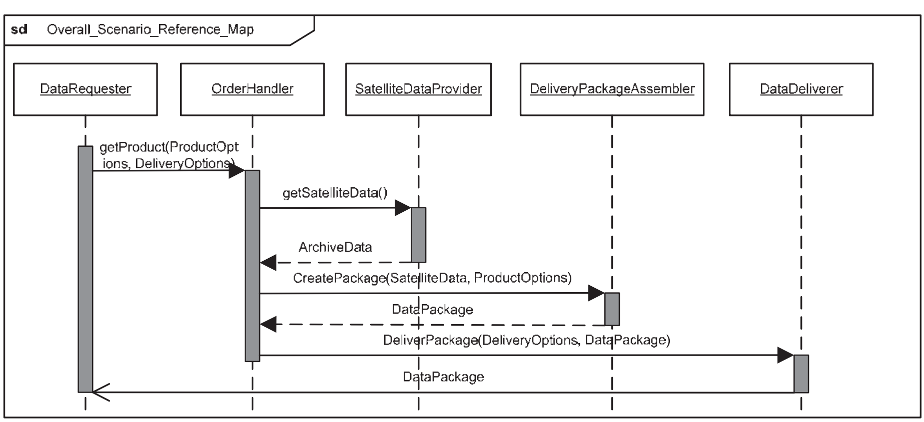

Fig. 2: Interactions typical for generation of a reference map for disaster scenarios.

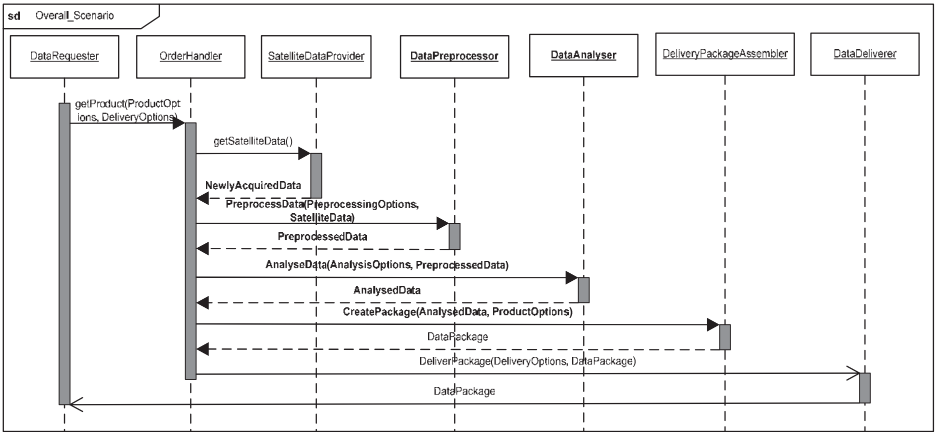

Fig. 3: Interactions typical for generation of a damage map.

A map concerning the special circumstances of a disaster is the next map needed. This map shall be called **damage map**. In Fig. 3 the much more complex actions needed for creation of a damage map are depicted. The differences from requirements of a reference map are scale (1 : 50 000 to 1 : 10 000) and availability (24 hours after ordering).

The main difference between a reference map and a damage map is the data needed to produce these maps. A reference map is a standard map of the area of interest. It has been created prior the disaster and is not disaster specific. The damage map uses satellite images created after the disaster. It is disaster specific and is analysed in detail (as depicted in Fig. 3).

The implementation of the scenarios leading to a damage map shall now be described for the satellite data providers RapidEye and Infoterra.

3 RapidEye

The effective and rapid imaging of large area disasters as applied in the DeSecure project requires imaging activites immediately following the disaster event. The RapidEye satellite constellation of five identical satellites is well suited for disaster mapping tasks as it provides multispectral imaging in 6.5 m resolution, a swath width of 77 km and a high area revisit rate. The capability of RapidEye‘s image acquisition workflows to successfully handle distaster-related special imaging orders were verified and repeatedly demonstrated within the DeSecure project.

3.1 *The RapidEye Mission*

The RapidEye Satellite constellation was successfully launched in August of 2008. All five satellites were successfully deployed and are in phase. Detailed information about the RapidEye system is given in (Tyc et al. 2008).

3.2 *Standard RapidEye Image Ordering and Processing Workflow*

RapidEye uses a flexible ordering and processing workflow. The workflow begins when an image order is entered by a Customer Service Representative (CSR) into the RapidEye Order Handling System (OHS). The OHS provides the order information for the following processing steps.

Following a positive decision during the next planning session, the tasked imaging schedule is uploaded to the satellite constellation from the RapidEye facility in Brandenburg an der Havel, Germany. After image acquisition, the collected data is downloaded via a receiving station located in Spitsbergen, Norway. The image data is transferred to the Brandenburg facility for further processing. Derived image products are in turn generated and provided via a „drop-box“ for FTP access to the customer.

Special Order Requests for Disaster Imaging for DeSecure

To enable the rapid imaging on short notice, such as to map natural disasters, a dedicated workflow was defined (RapidEye Special Order Request) to enable the processing of short term image orders of high priority. For this, at the beginning of each planning session the stack of incoming orders is checked for Special Orders. If this applies, the acceptance and prioritisation of the Special Orders is ensured by the (human) operators.

The originally scheduled trials and subsequent evaluation of the Special Order Process were rendered obsolete by real world scenarios: The Special Order Process underwent its first successful application in February 2009 for the mapping of bush fires in Australia.

Daily Imaging Tasking Planning (Fig. 4)

After initially starting out with a single daily planning cycle, RapidEye conducts planning sessions twice every day since 2009 to schedule the imaging tasking of the satellite fleet. The daily planning schedule is as follows:

06:00 UTC: The planning of imaging from 13:00 UTC to 24:00 UTC is done, based on existing image orders and global cloud forecasts. This planning focuses on the imaging activities covering both South and North America.
14:00 UTC: Planning of imaging from 00:00 UTC till 13:00 UTC on the following day, based on image orders and the latest cloud forecasts. This planning phase focuses on Australia, Asia, Europe and Africa.

The results of each planning are subsequently handed to the satellite control centre to be uploaded to the individual satellites via the RapidEye facilities in Brandenburg an der Havel, Germany.

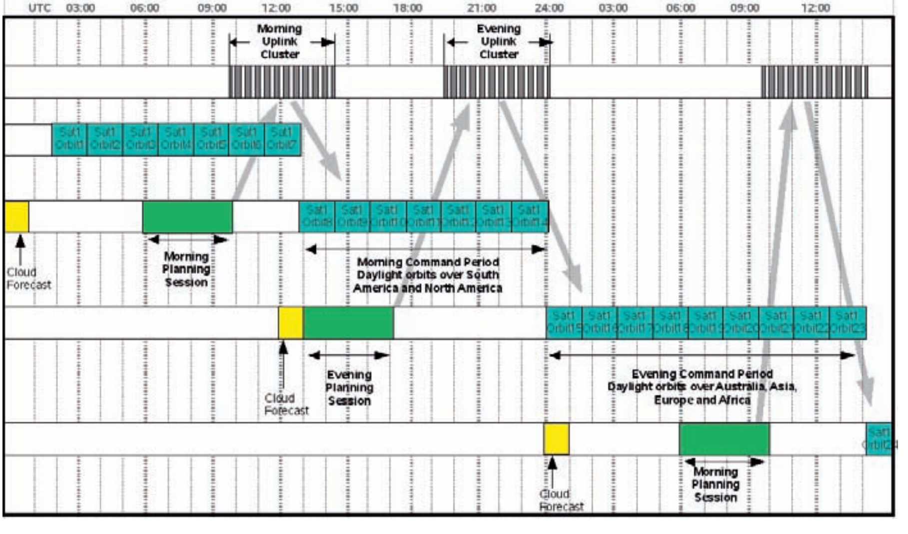

Fig. 4: RapidEye daily image acquisition planning workflow. Each planning phase (6:00 UTC and 14:00 UTC) is followed by the upload of an updated imaging schedule to the satellites. Upon successful image acquisition, the imagery data is downloaded via a ground station on Spitzbergen (Svalbard), Norway.

Time Constraints

The time span between the "go" decision to image an area of interest and the actual imaging event can range between 90 minutes to 13 hours. The reason for this is the time difference in universal time between the overpass of the tasked satellite over the ground station in Brandenburg and the next overpass over the area of interest.

Fig. 5 gives the times in universal time (UTC) when the satellite constellation passes areas of interest during the daylight hours. After successful image acquisition, the data download via Spitsbergen and transfer to the RapidEye facilities in Brandenburg, Germany, can take up to 60 minutes.

3.3 *Test Cases*

The Special Order Request workflow was successfully applied to provide imagery for the following six worldwide disaster imaging activities within the scope of the DeSecure project.

- 2009 February, Australia: Bush Fires
- 2009 April and 2010 April, Namibia: Caprivi flooding events
- 2009 June, Greece: Bush Fires
- 2010 March, Haiti: Earthquake
- 2010 April, Chile: Earthquake / Tsunami
- 2010 April, Gulf of Mexico: Oil spill

3.4 *RapidEye Conclusion*

RapidEye's Special Order Request work flow for rapid imaging for large disasters has been successfully tried and tested within the DeSecure project. Instead of a planned test run, the work flow performance was confirmed in real world situations due to sudden demand. Caused by system design constraints, minimal response/turnaround times from placing an order until imagery delivery (for special order completion) exist. It was confirmed that the system can successfully provide imagery data to the Svalbard station within a time frame from 90 minutes to 13 hours after a positive planning decision. Within additionally up to 60 minutes the image data were available in RapidEye for processing and delivery to the customer. The specified response times were always met when the Special Order Process was used for six different disaster imaging tasks on several continents in the DeSecure project.

The work flow for Special Order Requests was and still is under permanent review and optimisation. Improvements could be achieved in the order submission to RapidEye, the implementation of orders into the planning system, the improvement of processing speed and the delivery process of image data to the customer.

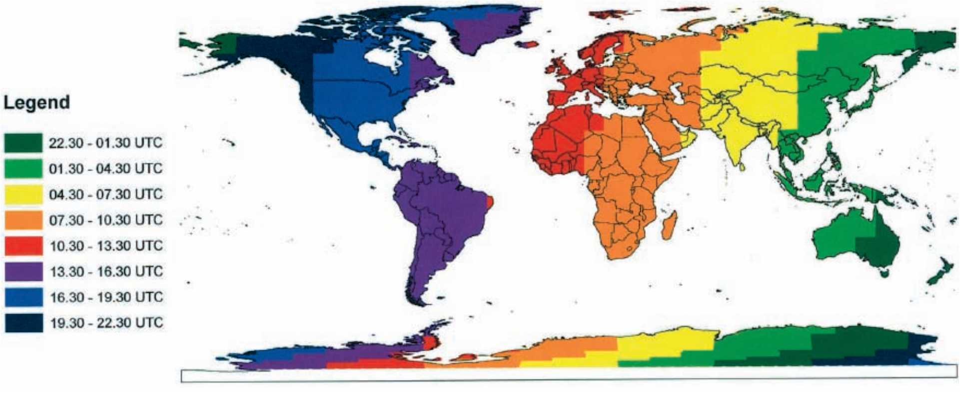

Fig. 5: Daily timeslots for satellite passes: Schematic overview of the daily imaging times by the the RapidEye satellite constellation. Example: The imaging of central and western Europe can only occur between 10:30 und 13:30 universal time. The imaging of Haiti (Caribbean) or the Gulf of Mexico only occurs between 13:30 to 16:30 hours universal time.

4 TerraSAR-X

In case of a crisis situation rapid delivery of remote sensing data is of utmost importance to serve the user community with early information to support crisis intervention. TerraSAR-X due to its weather independent SAR instrument is well suited for disaster mapping applications and offers different imaging modes ranging from very high resolution SpotLight mode (1 m) to StripMap mode (3 m) up to medium resolution ScanSAR mode (18.5 m). In the frame of the DeSecure project the near-real time data acquisition capability of the combined TerraSAR-X Ground Segment operated by DLR and the Commercial TerraSAR-X Service Segment operated by Infoterra were analysed in order to identify and implement potential improvements to provide customers more rapidly with data and first results. The focus was on optimising the entire processing chain from data ordering up to delivery to the final customer.

4.1 *The TerraSAR-X Mission*

TerraSAR-X is a German radar satellite. It carries a high frequency X-band SAR sensor which can be operated at different imaging modes including high resolution SAR imagery that had not been available by commercial missions from space before. The mission has been implemented as a Public Private Partnership (PPP) between the German Ministry of Education and Science (BMBF), German Aerospace Centre (DLR) and EADS Astrium GmbH.

DLR operates the satellite control system and the payload ground segment for receiving, processing, archiving and distribution of the X-band SAR data. DLR is also responsible for instrument calibration, the operations and the scientific use of TerraSAR-X data.

Infoterra holds the exclusive commercial exploitation rights, operates the commercial service segment and provides all commercial customers access to TerraSAR-X data. Due to its high resolution TerraSAR-X data are subject to a sensitivity check according to the German Satellite Security Act (SatDSiG). This law aims to protect the foreign policy and security interests of Germany.

4.2 *TerraSAR-X Overall Response Time*

TerraSAR-X overall system response times for tasking, sensing, reception and delivery of SAR Image Products are presently determined by a system architecture composed of one spacecraft in orbit and two ground stations, one dedicated for data reception located in Neustrelitz, Germany, and one station dedicated for command uplink, located in Weilheim, Germany. Therefore, orbital geometry, geographic latitude of area of interest and nominal incidence angle ranges of TerraSAR-X dictate the frequency with which an area of interest can be imaged by the satellite, with variations ranging from 1.5 to 11 days. Once

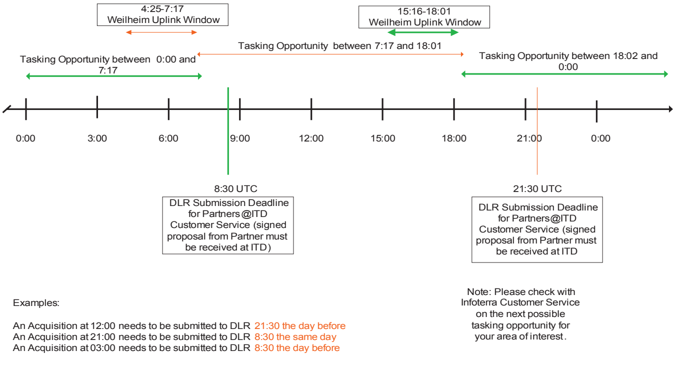

Fig. 6: TerraSAR-X timelines and submission deadline.

one or several accesses over a given site have been identified, the earliest possible access is identified in relation to its submission deadline. This deadline is the last possible opportunity to schedule a particular acquisition in the next 6-18 hours. The Fig. 6 illustrates the principle.

Two deadlines per day for placing orders exist at 8:30 UTC and 21:30 UTC. These deadlines correspond to tasking opportunities within the next 6 to 18 hours. It is important to note here that it is the sensing time of a selected acquisition (and therefore, its geographic location in the world) that determines the corresponding submission deadline.

Once the requested image has been acquired it will be down loaded via the Neustrelitz Groundstation and in case of a NRT request immediately processed to L1B products based on the available predicted orbit product. The final image products are then delivered to a customer pick up point.

4.3 *Optimisation of the TerraSAR-X Order Workflow*

The existing ordering and processing workflows have been analysed in the frame of the DeSecure project. The analysis has revealed that improvements could mainly be realised in following areas:

- Improved operational procedures to handle customer registration.
- Possibility to order long uninterrupted strips of TerraSAR-X StripMap data instead of single StripMap scenes.
- Automisation of the order workflow to reduce manual operator interaction.
- Improved order status handling to foster the overall system performance.
- Optimised sensitivity check according to German Satellite Security Act (SatDSiG).
- Automated delivery process to accelerate the submission of final products.

Consequently, the identified areas for improvement were implemented in the Commercial Service Segment operated by Infoterra and the TerraSAR-X Ground segment operated by DLR.

Several real life tests were conducted to assess and document the achievements that could be gained. The results show that a considerable speed-up can be realised by the implemented new features.

4.4 *TerraSAR-X Conclusion*

The TerraSAR-X order and processing workflow for NRT applications has been analysed in detail and several areas for improvement were identified and subsequently implemented in the existing infrastructure leading to substantial time savings. In particular, following conclusions can be drawn from the available test results:

Even with only one satellite in orbit and one receiving station it could be shown that for most areas in Europe image data can be provided within a few hours, when a tasking opportunity has been established, and a NRT Product is sufficient. Outside Europe the overall response time is mainly depending on the next possible acquisition opportunity.

For the test cases analysed the time from downlink to delivery of the final orthorectified image results in about 2 hours which can be regarded as an excellent result.

5 Optimised Satellite Data Pre-Processing

For an efficient use of geo-information before or during a crisis of any kind, all information should be provided in a geographic information system (GIS). This requires the data to be orthorectified. This is a pre-processing step which has to be done for every satellite image.

Different established methods exist already for the orthorectification of satellite data; both for optical (e. g., RapidEye) and SAR scenes (e. g., TarraSAR-X). In the project DeSecure different software packages were analysed with regard to geometric accuracy, degree and potential of automatisation, computing times and therewith near-real time capabilities, the extendibility and potential for optimisation, user friendliness, and which satellite data are supported by each program. When a potential for optimisation was detected, it was carried out within the project. For the comparison different test cases were processed with all software packages and the results were analysed qualitatively and quantitatively.

5.1 *Orthorectification of Optical Satellite Data*

For the orthorectification of optical satellite data four software packages (Tab. 1) were evaluated (Hoja et al. 2008). All results were collected yielding in a "methods-sensors matrix". For most common optical satellite data, all software packages create results of high accuracy in less than 45 minutes. Therefore the selection of the program to be used can be done by other criteria, e. g., which program one is used to or computing times. Especially, we emphasise to use a program, which is already existent and you are used to its handling. In this case, the failure probability is lowest and you can expect fast and reliable results in crisis situations.

For the mapping of crisis situations a large number of satellite sensors resp. their data is used. The integration into a processing chain is only possible, when all necessary information like satellite orientation or rational polynomial coefficients (RPC) are delivered in a known and unchanged format. Each change of the data format as often done tacitly by the data provider results in a (time) costly error search and therewith a delay of the orthorectification.

5.2 *Orthorectification of SAR Satellite Data*

Common methods for SAR geocoding as used by the project partners (Enhanced Geocoding Processor EGEO and TerraSAR-X Ground Service Segment TSXX) were evaluated similarly to the optical analysis in regard to accuracy and optimisation potential.

The performance of the EGEO processor (Huber et al. 2004) was analysed with ALOS PALSAR, RADARSAT I and II scenes. First the sensors were implemented in EGEO. The orthorectification of the test scenes with high resolution lasted 18 to 21 minutes. Lower resolutions induce shorter computing times. The time demand of rapid mapping is therefore met. The results of the orthorectified RADARSAT II scenes show very good position accuracy. However the processing of the orthorectified ALOS PALSAR and RADARSAT II scenes achieve a deficient accuracy. Reason is the imprecise position of the orbit. Further results show that improvements can only be achieved with the help of ground control points (GCP).

In a theoretical analysis the orbit measurement accuracy and the digital elevation model (DEM) quality were identified as the two main factors influencing the geo-location accuracy of SAR images. Both factors were further ana-

Tab. 1: Overview of analysed software packages.

Software package	Availability	Orthorectification with orientation data	Orthorectification with RPC	Computing time [min]	Image matching
XDibias	Research	OK	OK	15 to 45	OK
Erdas Imagine	Commercially	OK	OK	5	NO
ENVI	Commercially	OK	OK	30	OK
PCI Geomatics	Commercially	OK	OK	5 bis 10	NO
HALCON	Commercially	NO	NO	–	OK
MIL	Commercially	NO	NO	–	OK

lysed for TerraSAR-X data also with respect to NRT scenarios. In order to analyse the influence of the DEM quality, test sites with different terrain conditions were selected (flat to alpine terrain). The analysis for all test sites confirmed the theory: DEM with a small height error result in an enhancement of the geo-location accuracy of the orthorectified TerraSAR-X product.

In a second step the orbit measurement accuracies for TerraSAR-X were investigated. They differ in delivery time and accuracy. Thus, the best accuracy is available with the science orbit, which is available approx. 5 days after acquisition. The orbit with the lowest accuracy is a prediction of the orbit (predicted orbit) and available directly after downlink of the data. The rapid orbit is available approx. 15 hours after the last satellite contact and provides a very good accuracy of 2 m and better (Fritz & Eineder 2009). The results showed that the geo-location accuracies reached with the science and the rapid orbit were very similar. The difference between this two orbit precisions is nearly not measurable (approx. 0.5 meters). For NRT processing of TerraSAR-X scenes always the predicted orbit is used. The geo-location accuracy reached for the predicted orbit is strongly variable (5 to 34 meters). However, the accuracy is much better than the specification (~700 meters). For the tests conducted in this study the bad orbit accuracy did not result in strong artefacts caused by the not fitting DEM. Thus, the orthorectified products with the predicted orbit might be a first input for further NRT applications. Nevertheless, for cases where a good geo-location accuracy of the images is essential for further processing, it might be more efficient to use directly the rapid orbit.

Another possibility is to use GCP in order to enhance the pixel location accuracy if the orbit accuracy is not sufficient. Different tests were performed resulting in an improvement of the horizontal accuracy of the images in the NRT case. This is valid for manually selected points as well as for the use of points provided within a data base. It has to be considered that point identification and precise point determination in SAR images is often difficult and time consuming and requires reference data.

5.3 *Image-to-Image Registration*

Image-to-image registration (Matching) of satellite data of different acquisition dates serves the geocoding (automatic GCP detection), but is also an important pre-processing step for change detection after a crisis to provide the high relative accuracy of the images. For the image matching different procedures are available (investigations within the project DeSecure):

- Matching of optical data (Evaluation of existing methods).
- Matching SAR data (Development of an automated process, analysis of the optimisation potential for „chip matching“).
- Registration of optical with SAR data (Development of automated methods).

An evaluation of image matching software tools was realised with regard to accuracy and optimisation potential. Four software packages (Tab. 1) were analysed. Main result is that XDibias delivers the highest accuracy and is easy to use due to available scripts. XDibias is the only package that uses a local least squares matching and not only a correlation-based matching like all commercially available programs. Therefore, the most reliable results are produced by XDibias; however, computing time is higher than for all other software packages.

A prototype for a fully automatic orientation of SAR images was developed. The goal is to determine a precise orbit for geocoding by image-to-image matching between a NRT image and a reference SAR image. The approach uses a new algorithm for feature extraction developed in computer vision by Lowe (2004). No prior information about the position of the images or the overlapping parts is needed. The point operator extracts points with scale- and rotation-invariant descriptors (SIFT features). After this the points are matched by using the SIFT parameter descriptors with an extended matching scheme. The resulting points of the reference image are used as GCP for an adjustment of the SAR imaging geometry of the NRT image. This achieves results equivalent to a high precision orbit. The results show that the approach can be used for a wide range of scenes with different SAR sensors, different incidence angles, different overlap extensions, and even different SAR frequencies. The results are very reliable but depend on well structured image content.

Another method to improve the geocoding besides image-to-image registration is the reusage of GCP points for the orthorectification of recurring acquisitions of an area by a so-called chip matching, which is based on an image-to-image matching approach. For each GCP a small area is cut from the image and saved in a database together with its coordinates. Almost the same pixel location accuracy was achieved for orthorectified images based on the science orbit information and orthorectified images based on the predicted orbit accuracy and GCP collection. Different polarisations or seasonal changes did not affect the matching results significantly. But the tests showed that the impact of the incidence angle is significant.

Finally, two different methods (mutual information, MI, and scale-invariant feature transform, SIFT) for image-to-image registration were developed and combined to extend their applicability to multi-modal SAR-optical and SAR-SAR registration. The performance of MI for very high resolution (VHR) remote sensing images was analysed and several methods were assessed to improve accuracy, applicability and processing time of VHR images acquired over dense urban areas. The potential of the methods to improve the orthorectification by image-to-image registration could be shown. Additionally, improvements in the SIFT processing chain were proposed resulting in an optimised technique for multi-modal SAR images (Suri & Reinartz 2010, Schwind et al. 2010).

Within the limit of the project DeSecure a large amount of optimisations was completed both, within the workflow of the satellite data systems RapidEye and TerraSAR-X, and regarding the orthorectifiing preprocessing, which has to be done for all satellite images.

References

Fritz, T. & Eineder, M., 2009: TerraSAR-X Basic Product Specification Document. – TX-GS-DD-3302, Issue 1.6.

Hoja, D., Schneider, M., Müller, R., Lehner, M. & Reinartz, P., 2008: Comparison of orthorectification methods suitable for rapid mapping using direct georeferencing and RPC for optical satellite data. – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences **37:** 1617–1624.

Huber, M., Hummelbrunner, W., Raggam, J., Small, D. & Kosmann, D., 2004: Technical Aspects of Envisat ASAR Geocoding Capability at DLR. – ENVISAT/ERS Symposium, Salzburg, Austria.

Lowe, D., 2004: Distinctive image features from scale-invariant keypoints. – International Journal of Computer Vision **60** (2): 91–110.

Schwind, P., Suri, S., Reinartz, P. & Siebert, A., 2010: Applicability of the SIFT Operator to Geometric SAR Image Registration. – International Journal of Remote Sensing, **31** (8): 1959–1980.

Suri, S. & Reinartz, P., 2010: Mutual Information-based Registration of TerraSAR-X and Ikonos Imagery in Urban Areas. – IEEE Transactions on Geoscience and Remote Sensing **48** (2): 939–949.

Tyc, G., Steyn, J., Hannaford, N., Gebbie, J., Stocker, B., Baker, A. & Oxfort, M., 2008: RapidEye – A cost-effective earth observation constellation. – IAC-08-B4.3.03 International Astronautics Conference 2008.

Addresses of the Authors:

Danielle Hoja, Anna Wendleder & Maximilian Schwinger, DLR e.V., Münchner Straße 20, 82234 Weßling, Tel.: +49-8153-28-1418, Fax: -1443, e-mail: Vorname.Nachname@dlr.de

Peter Löwe, Harald Konstanski & Horst Weichelt, RapidEye AG, Molkenmarkt 30, D-14776 Brandenburg an der Havel, Tel.: +49-331-8904-334, Fax: -101, e-mail: loewe@rapideye.de

Nadine Kiefl & Jürgen Janoth, Infoterra GmbH, Claude-Dornier-Strasse, D-88090 Immenstaad, Tel.: +49-7545-8-4291 e-mail: Juergen.Janoth@infoterra-global.com

Manuskript eingereicht: Juni 2010
Angenommen: September 2010