TerraSAR-X and TanDEM-X: Revolution in Spaceborne Radar

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ملخّص : مازالت وستبقى الصوّر الجاهزة تجارياً ضرورية للمنظمات المدنية و العسكرية التي تجمع عدة أنواع من المعلومة الجغرافية الفضائية . يعدّ الوصول إلى معطيات الكشف عن بعد ذات دقة التمييز العالية قاعدة أساسية للإتخاد القرار، خاصّة في الأوقات الحرجة. إذا تمّت مراعاة الإتفاقيات الدوّلية، إنشاء وحدات عسكرية للحفاظ على السلام الدوّلي أو المهام البشرية ، أو القيام بتمارين تقنية مشتركة مع دوّل أخرى .
في الوقت الحاضر، تحتاج عادة المنظمات إلى اللجوء إلى المعطيات ذات دقة التمييز العالية المكتسبة بالكاشف البصري – غالبا في عملية طويلة. يمهّد القمر الإصطناعي الرداريTerraSAR-X ، في مرحلة لاحقة مع TanDEM-X بسعته للإقتناء المعطيات المتممة تقريبا صحيحة للإستعمال التام لمجموعة المعطيات في المدار للإحتياجات الخرائطية في الأوقات الحرجة.

Résumé : Les images disponibles commercialement sont et resteront indispensable pour les organisations civiles et militaires qui collectent plusieurs types d'information géo spatiale. L'accès fiable aux données de télédétection à haute résolution est une base essentielle pour une prise de décision bien informée, en particulier dans les situations à temps critique. Si on respecte les accords internationaux, fournir des contingents militaires pour le maintien de la paix internationale ou missions humanitaires, ou mener des exercices techniques joignent avec les autres pays.
Aujourd'hui, les organisations ont besoin de recourir habituellement aux données à haute résolution acquises par les détecteurs optiques – souvent une longue opération. Le satellite radar TerraSAR-X, et dans une étape ultérieure avec TanDEM-X avec ces capacités d'acquisition des données complémentaires à temps presque réel, offre une nouvelle approche entière à l'usage d'ensemble de données en orbite pour les besoins de cartographie dans les situations à temps critique.

Abstract : Commercially available imagery is and will remain indispensable to civilian and military organizations gathering various types of geo-spatial information. Whether fulfilling international agreements, providing military contingents in international peacekeeping or humanitarian missions, or conducting joint technical exercises with other countries – a reliable access to timely, high resolution remote sensing data is an essential basis for well-informed decision making, particularly in time-critical situations.
Today, organizations with those needs customarily resort to high resolution data acquired by optical sensors – often a lengthy operation. The radar satellite TerraSAR-X, and at a later stage together with TanDEM-X with it's complementary near-real time data acquisition capabilities, offer a whole new approach to the use of space-borne datasets for mapping purposes in time-critical situations.

1. Introduction

Due after the commissioning phase since January 2008, EADS Astrium's new radar satellite TerraSAR-X provides Earth observation data of unprecedented quality, with a resolution of up to one metre, for increasingly diversified commercial as well as for scientific applications. Its scheduled lifetime will be 5 years. However, the whole SAR programme will last more than 10 years.

Commercial users require detailed data adapted to their individual requirements, available quickly and reliably, independent of daylight and weather conditions. The design and performance of TerraSAR-X will exactly meet these requirements. The Synthetic Aperture Radar (SAR) instruments of the spacecraft supply extremely detailed radar images, day and night, under all weather conditions. The acquired data is the basis for a wide variety of products and services, such as highly sophisticated client-specific image interpretation, topographic maps up to a scale of 1:10,000, geo-spatial databases and terrain analysis much in demand for a wide scope of applications. Other application sectors include environmental planning, land cover and natural resource exploration, regional and urban development, catastrophe response and relief, insurance and risk assessment as well as applications in border control, security and defence.

New-quality data records, as provided by TerraSAR-X, will also offer a vast number of new research incentives, for instance in forestry, ecology,

Images originales : http://www.infoterra.de/image-gallery/images.html

geology, hydrology and oceanography. The smallest movements of the Earth's surface due to plate tectonics, volcanism, earthquakes, and land slides are further challenging fields of application of TerraSAR-X interferometry.

The space mission TerraSAR-X is the first German space project implemented under a Public Private Partnership (PPP). Cooperation partners are the German Aerospace Centre (DLR) and EADS Astrium. Under this construct DLR will be responsible for the scientific use of the TerraSAR-X data, whereas commercial marketing will be undertaken exclusively by Infoterra GmbH, a wholly-owned EADS Astrium subsidiary specialising in the collection, processing, and distribution of air- and spaceborne imagery and value-added products.

2. Demand for High resolution data

Commercially available imagery is and will remain indispensable to organizations gathering intelligence information. Whether fulfilling international agreements, providing contingents in international peacekeeping or humanitarian missions, or conducting joint exercises with other countries – a reliable access to timely, high resolution remote sensing data is an essential basis for well-informed decision making, particularly in time-critical situations.

Today, organizations with those needs customarily resort to high resolution data acquired by optical sensors with which huge area coverage can only be accomplished with large temporal offsets. TerraSAR-X, with it's complementary near-real time data acquisition capabilities, offers a whole new approach to the use of space-borne datasets in time-critical situations.

The spacecraft TerraSAR-X delivers unique, novel quality SAR satellite image data with a resolution of up to one metre, which can significantly augment the capabilities of armed forces, homeland security, and intelligence agencies, creating both tactical and strategic advantages. Reduced image speckle through multilooking and the presence of radar shadows of man made objects are important features of the high resolution TerraSAR-X images which will by far enhance the image interpretability over that of medium resolution SAR systems.

Besides of updated high resolution imagery of the Earth's surface, the availability of precise information on terrain evaluation is strongly requested by users of geo-spatial data. Currently most areas in the world are covered by an elevation grid of poor quality in terms of point density and height accuracy (ERS-1/2 Tandem, SIR-C/X-SAR, SRTM, GTOPO30). In order to close this gap of information towards the third dimension TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) is a German program for a new generation SAR satellite operating at X-band in single pass SAR interferometry. The single pass SAR interferometric constellation, comparable to stereoscopic survey missions, is realized by two independent X-band satellites, TerraSAR-X together with TanDEM-X, flying in a close formation, quite often less than 1 km. The mission goal is to deliver a global digital elevation model characterized by a height accuracy of better than 2 m. The additional spacecraft TanDEM-X is already financed through a PPP agreement between DLR and EADS Astrium and will be launched in 2009.

The increasing demand of sophisticated geospatial data sets requires appropriate and precise planning documents in all the three dimensions. However, a continuous and up-to-date acquisition by optical sensors or airborne platforms is strongly limited either by unfavourable weather conditions or inefficient mission scenarios. Therefore, the easy access to the high-resolution radar missions TerraSAR-X and TanDEM-X gives the global remote sensing community the possibility to participate in one of the most ambitious space programs.

The System TerraSAR-X will deliver high resolution SAR images with a ground sampling distance up to 1m, in combination with unique satellite agility: The electronically steered antenna allows acquiring physically separated areas of interest within seconds without rolling the whole satellite. The satellite is mainly described by:

- TerraSAR-X is operated at X-band at 9.65 GHz. Even pure visual interpretation will profit from the fact that the short wavelength shows more spatial detail than longer wavelengths.
- The chirp bandwidth, an indicator of the spatial accuracy level, is with 300 MHz the best performance currently in space.
- Single, dual and quadruple polarizations allow for a more complex description of the areas and objects on the ground. Their availability depends on the imaging mode and always is a trade-off with the spatial coverage and swath width.
- Radiometrically calibrated data allow for an easy comparison between scenes.
- TerraSAR-X is both, daylight and weather independent, i.e. the system can record data at night and through clouds or dense smoke cover.
- The system features a quick site access time of 2.5 days to any point on Earth at 95% probability.

- TerraSAR-X features a unique agility: it is possible to switch between its three different imaging modes and various polarisations within only 1 to 3 seconds, corresponding to surface acquisition offsets of only 7 to 20 kilometres.
- Time-critical data can be downloaded within seconds after acquisition to mobile ground stations on-scene, thus enabling near-real time data processing.
- Anonymous and encrypted processes guarantee an unobjectionable confidentiality.
- Furthermore, the satellite's very high resolution of up to 1 m and its high radiometric accuracy, make TerraSAR-X an ideal sensor to support sensitive decision-making in time-critical situations.
- Satellite Tasking twice a day and priority settings for the ordered data takes allow for quick turnaround times in data delivery and late order changes.

TanDEM-X will be an almost identically constructed system with some slight modifications for the necessary synchronization link between both satellites.

3. Image Modes and Products

In the standard operating mode (so-called single receive antenna) image data in three different imaging modes can be acquired: SpotLight, StripMap and ScanSAR:

- **SpotLight** with up to 1 m resolution (10 km (width) x 5 km (length) image size) – the most sophisticated radar imagery available on the market: In flight direction, the radar beam can be steered like a veritable spotlight, illuminating a particular ground scene for the longest time period possible, thus achieving a 1 metre class resolution as well.
- **StripMap** with up to 3 m resolution (30 km x 50 km standard scene size, extendable up to < 4,000 km acquisition length) – the ground swath is illuminated with continuous sequence of pulses while the antenna beam is fixed in elevation and azimuth. This results in an image strip with a continuous image quality (in flight direction). Besides dual polarization StripMap images will even be available as quadruple polarisation data, which allows for a more complete statistical description of the observed scene.
- **ScanSAR** with up to 16 m resolution (100 km x 150 km standard scene size, extendable up to < 4,000 km acquisition length) – Areas up to 400,000 km² anywhere on the globe can be covered in this image mode within only one orbit. In the ScanSAR mode, a swath width of 100 km (and even more) will be achieved by scanning four adjacent ground sub-swaths with quasi-simultaneous beams, each with different incidence angle.

The Basic Image Products generated from these three imaging modes are:

- Single Look Slant Range Complex (SSC) with amplitude and phase information in slant range geometry.
- Multilook Ground Range Detected (MGD) corrected to WGS84 with an average terrain height for slant range to ground range projection.
- Geocoded Ellipsoid Corrected (GEC) corrected to WGS84 with an average terrain height.
- Enhanced Ellipsoid Corrected (EEC) corrected to WGS84 with a digital elevation model (DEM).

These products are available as CEOS Level 1b data sets, can be absolutely radiometrically calibrated using the accompanied information and can be delivered as either a radiometrically or a spatially enhanced product. The spatial extent corresponds to the area accessible by the TerraSAR-X standard scene.

In addition to these basic products, a set of value-added products is available, which are spatially oriented at the users region of interest which can be larger than a satellite scene.

The Orthorectified Image (ORISAR) is a geocoded image with highly precise terrain correction included. All those terrain distortions inherent in satellite imagery, particularly in areas with rough terrain have been removed. The orthorectification process uses high precision digital elevation models, so that the pixel location accuracy in comparison to EEC product is increased.

The orthorectified image is also available as an image mosaic (MCSAR) or a customer defined area of interest, i.e. a subsetted image product which covers a predefined geographical area.

Fig. 1 OM^{SAR} OrthoMap Customized map sheet layout.

Radiometric correction and normalization methods improve the orthoimage even more: The RANSAR product provides calibrated backscattering values which are necessary for quantitative analysis methods on the orthorectified images.

Ascending/Descending Merge (ADMSAR) Typical charac-teristics of SAR images are the radar shadows which are usually visible and may not be a helpful attribute because they obscure parts of the area under investigation. If the combination of SAR images from ascending and descending right looking orbits is used for image analysis, a reduction of the impact of layover, and radar shadow effects can be achieved. The ADMSAR product includes this orbit merge. Mosaics (MCSAR) or Oriented Images (OISAR) are optionally available as ADMSAR. The ADMSAR is of particular interest for area with steep mountainous terrain, where shadow and layover can disturb the analysis.

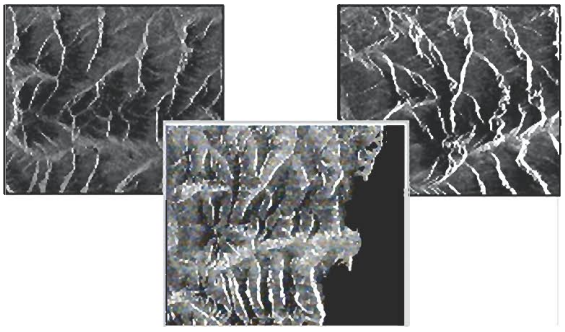

Fig. 2 ADM^{SAR} Ascending/Descending Merge sample product (middle) through combination of ascending (left) and descending orbits (right).

4. The Subsidence Map (SUB^{SAR})

provides information on long-term surface displace-ment in urban areas and settlements. Such vertical surface dis-place-ment may be caused e.g. by tec-tonics, subsurface mining, earthquakes. The resulting maps can be used for risk diagnostics. The displacement is calculated from image pairs using Differential Interferometric SAR (DInSAR) or Persistent Scatterer Interferometric SAR (PSInSAR). These are images of the same area observed under a slightly different squint angle. TerraSAR-X can acquire these image pairs with repeat pass interferometry with a temporal off-set of 2.5 to 11 days depending on the geographical location of the area of interest. The longest time interval will be reached at the equator, the shortest the closer the location is to the poles. The detectible difference in height is related to the wavelength and thus in case of TerraSAR-X is a fraction of approx. 3cm.

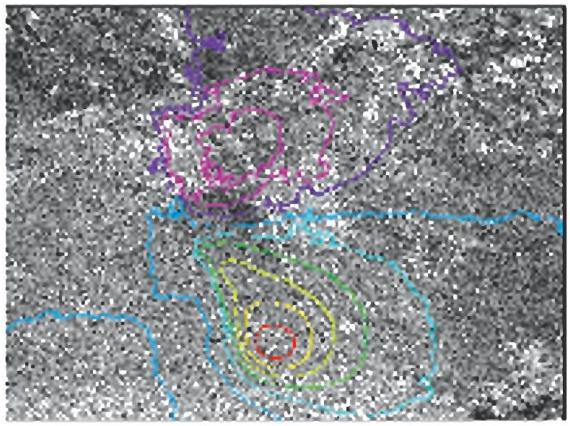

Fig. 3 CDM^{SAR} Change Detection Map - Earthquake.

5. Change Detection Map (CDM^{SAR})

can provide information on long-term Land use/Land cover changes e.g. in surface sealing and urban sprawl. Such information can be used e.g. for urban/construction monitoring, urban planning appli-cations or topographic map up-dates. It is generated from repeat pass inter-ferometric image pairs over an area of interest in which image coherence changes are detected. Changes are mapped of a period of time long enough to be significant for the phenomenon to be mapped, i.e. the period depends on the mapping topic of interest and is defined by the customer. The product is generated from StripMap or SpotLight images.

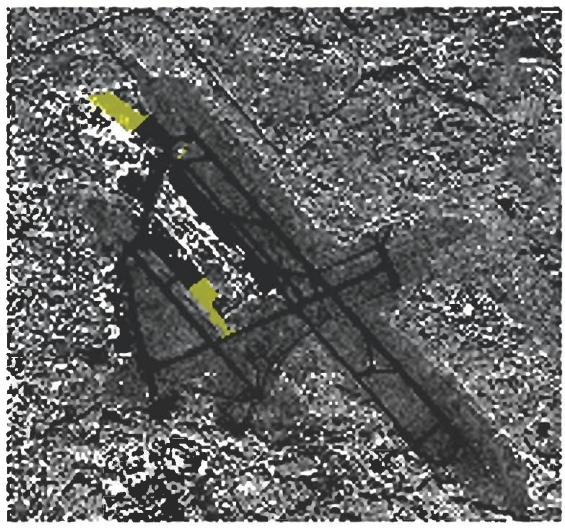

Fig. 4 CDM^{SAR} Change Detection Map - Airfield.construction

6. Time-Critical Applications

Image interpreters may get into analyzing capacity problems e.g. in case of crises. Infoterra GmbH

offers additional products and services that can be adjusted according to customers needs in order to support image interpreters during peak work loads. For example, the customer can define the depth and quality of the image interpretation of the ordered product.

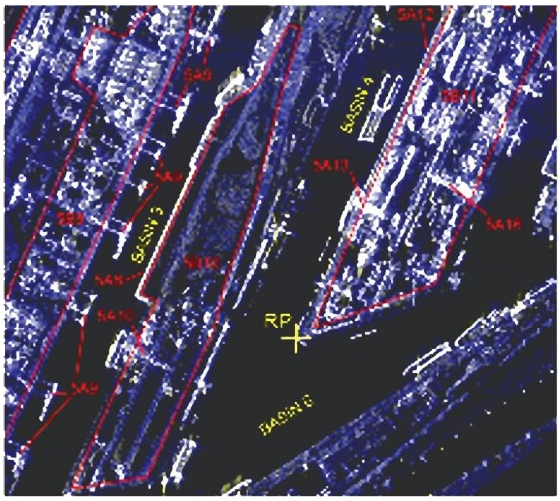

Fig. 5 Annotated dual polarisation SAR image. Harbour of Duisburg, Germany.

- Clearly defined objects or infrastructure characteristics are highlighted and (pre-) interpreted.
- Interpretation keys could follow the NATO Standardization Agreement (STANAG) or others.
- Legends and map styles are adjusted to customers needs.

Thus, decision makers are relived from certain steps in the image analysis process and will gain support for their strategic decisions.

Other options for fast object extractions to create GIS layers are: Line elements (e.g. roads, power transmission lines, railways) through line detection and context evaluation or single man-made objects (e.g. bridges, storage tanks, lattice masts) through fast screening methods.

7. Digital Elevation Height

The TanDEM-X mission aims at generating a global Digital Elevation Model (DEM) with an extremely high accuracy corresponding to HRTI-3 specifications defined by the U.S. National Geospatial-Intelligence Agency (NGA). This goal will be achieved by means of a second SAR satellite TanDEM-X flying in a combined orbit with TerraSAR-X. Thus SAR image and DEM data will synchronously be available for the same site.

Commercial exploitation of TanDEM-X will benefit mainly from the global high quality DEM product, the associated update services, and the generation of topographic base data (image and contour line maps). Further applications with commercial potential will be implemented, based on the applications research results (e.g. moving target detection, super resolution, differential InSAR based monitoring).

The DEM quality domain that the TanDEM-X mission can provide is today dominated by offers based on airborne campaigns. There is currently no system or process available to provide a global service for HRTI-3 (z-accuracy better than 2 m) and in specific cases HRTI-4 (z-accuracy better than 1 m) DEMs with short response time. Those requirements of the important geospatial markets can only be fulfilled by globally operating a space-borne SAR system. Optical systems require cloud free weather conditions and therefore often fail to fulfil the global response time demand. Airborne systems lack in global mapping capability.

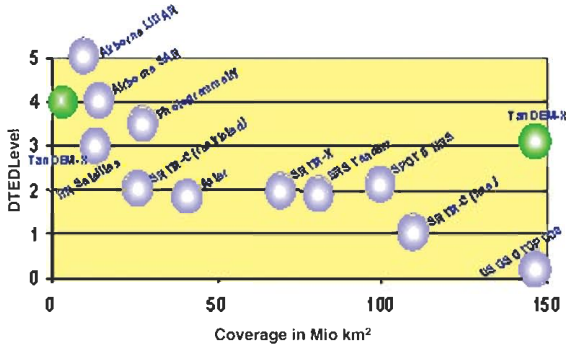

Fig. 3 Overview of available sensors and their digital elevation standard.

8. Geo-Information Service

8.1 Conpany profile

Launched in January 2001, Infoterra GmbH is a 100% owned subsidiary of EADS Astrium, Europe's leading space company. Infoterra was founded to prepare and conduct the commercial exploitation of TerraSAR-X and TanDEM-X data services as well as system capacities.

Infoterra was formed by spinning-off the 'Earth Observation Services' division of the former EADS Astrium GmbH, Germany, re-branding of the UK-based National Remote Sensing Centre Ltd., and the French ISTAR S.A. Infoterra has a 200-strong team of highly skilled staff, including experts in cartography, photogrammetry, forestry, agriculture, geological exploration, environmental management, and

telecommunications planning. In addition, Infoterra's staff is skilled in the development of systems software specific to the manage-ment of geographic data. Such a strong market-oriented positioning facilitates a prompt and flexible response to all enquiries within the geo-information community.

Infoterra is serving and supporting both public and private customers with geo-information on cartography, land use/ land cover, and forestry as well as with a focus on TerraSAR-X, GMES (Global Monitoring for Environment and Security), and thematic mapping services. Infoterra is ISO9001: 2000 and ISO 14001 certified and guarantees that all activities are performed according to internationally accepted quality and environmental standards.

8.2 Service Implementation

The TerraSAR-X as well as the TanDEM-X implementation will be carried out in a PPP frame (Public Private Partnership) between EADS Astrium GmbH and DLR. The observation capacity of TanDEM-X will be 50% for InSAR operations and 50% for compensating the TerraSAR-X capacity contributions to the InSAR mission. Through this capacity swap the nominal TerraSAR-X line can be maintained at committed service capacities. Infoterra GmbH will exploit the commercial mission part and sell the products and services globally, capitalizing on the customer base and sales network established for the TerraSAR-X based portfolio.

9. Summary

TerraSAR-X and TanDEM-X data and services will be a major component in many applications related the geospatial information. In the basic application TerraSAR-X will contribute to topographic mapping, time-critical reconnaissance, and land cover surveys which provide the core elements for any presentation or analysis of geographic information. In addition TanDEM-X will provide the third dimension in a new quality.

Depending on the information depth of the requested information categories, the derivation from SAR data might be very complex in specific cases. Based on the profound experience of the Germany-based Infoterra and its distribution and production partners TerraSAR-X / TanDEM-X data and services will be delivered globally and with the highest standard of accuracy, quality, reliability; and sustainability.

Started arly 2008, TerraSAR-X supports the use of other Earth observation data through its multi-scale, multi-temporal and multi-frequency/polarization observations of remote areas that were formerly almost impossible to map. TanDEM-X will follow in 2009.

Reference

Figure 1 - 3 : courtesy of Joanneum, Research, Austria.