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TerraSAR-X Mission: The New Generation in High Resolution Satellites

Jörg Herrmann
Alejandra González Bottero

Infoterra GmbH, 88039 Friedrichshafen, Germany
joerg.herrmann@infoterra-global.com; alejandra.gonzalez@infoterra-global.com

Abstract: While Earth observation from space in the past was mainly focused on scientific purposes, today data and the derived information products are increasingly used for various commercial applications. Potential users today are planning and consulting offices, food and natural resource industries, insurance companies or agencies. However, from a customer's point of view, the data and information supplied by current satellite missions have one considerable drawback: they only partially meet their requirements.
New data of enhanced quality are therefore needed for an increasing and sustained commercial exploitation of Earth Observation (EO) data. They must be more detailed, have a better thematic accuracy, and must be delivered faster and reliably independent of weather conditions and cloud coverage. According to Astrium studies, the data supplied by the newly developed high-resolution radar instruments (SAR - Synthetic Aperture Radar) are the ideal source of material for commercial applications.

Keywords: High Resolution Sensors, Remote Sensing, Synthetic Aperture Radar (SAR), Interferometry, Digital Elevation Model (DEM), Polarization.

1. Introduction

TerraSAR-X is a German remote sensing satellite program which will be the first commercially available radar satellite- cloud independent- to offer one meter resolution. The technologies involved are capitalizing on the long experience of ASTRIUM in spaceborne synthetic aperture radar (SAR) systems (SIR-C/X-SAR, SRTM, ERS, ASAR) as well as on German national technology developments that brought the active phased array X-band SAR to space qualification level in 2000. Currently, the Ground Segment and the Satellite sensor have successfully paased all final technical tests and wait for launch in the last quarter of 2006. TerraSAR-X services will be offered with long term continuity (10 years) with a follow-on spacecraft to be launched after 2010.

TerraSAR-X is the first satellite ever to be built in a Public Private Partnership (PPP) in Germany. In this partnership, the Federal Republic of Germany, represented by the German Aerospace Center (DLR), and Europe’s leading satellite company ASTRIUM GmbH have agreed to jointly bear the costs of constructing and implementing this X-band radar satellite. DLR procures the satellite, prepares the ground segment and will conduct the system operations. ASTRIUM GmbH co-invests into the supply of the satellite and launch service and invests into the commercial service segment, and in turn receives commercial exploitation rights. DLR will conduct science exploitation of the mission in an announcement of opportunity (AO) process.

In order to ensure the commercial success of the mission, ASTRIUM GmbH founded its 100% subsidiary Infoterra GmbH in 2001; the company being responsible for establishing a commercial market for TerraSAR-X data as well as TerraSAR-X-based geoinformation products and services. The marketing of TerraSAR-X services has been initiated in 2004. ITD has started to build a global distribution network involving data providers with regional focus or with an access to dedicated market segments.

2. TerraSAR-X Description

TerraSAR-X is a satellite with a right-side-looking X-band synthetic aperture radar (SAR) based on active phased array antenna technology [1].

The active antenna allows not only the conventional StripMap mode but also SpotLight and ScanSAR modes. **Table 1** summarizes the characteristic values of the orbit and altitude parameters, while **Table 2** summarizes the system parameters.

Table 1: Orbit and System Parameters

Orbit and Altitude Parameters	
Nominal orbit height at the equator	514 km
Orbits / day	15 2/11
Revisit time (orbit repeat cycle)	11 days
Inclination	97.44°
Ascending node equatorial crossing time	18:00 ± 0.25 h (local time)
Yaw steering	yes

Table 2: TerraSAR-X System Parameters

System Parameters	
Radar carrier frequency	9.65 GHz
Band	X-band
Wavelength	3.11 cm
Pulse repetition frequency (PRF)	2.0 kHz – 6.5 kHz
Range bandwidth	150 MHz / 300 MHz (advanced mode)
Polarizations	HH, VH, HV, VV
Nominal antenna look direction	right
Antenna width	0.7 m
Antenna length	4,8 m
Data access incidence angle range	15° - 60°
Incidence angle range for StripMap / ScanSAR modes	20° - 45° full performance
Incidence angle range for SpotLight mode	20° - 55° full performance
Maximum achievable resolution (in range)	0.65 m – 1.5 m @ 300 MHz (advanced mode)
Azimuth resolution	1 m – 16 m depending on imaging mode, incidence angle, and number of polarizations

3. Imaging Modes

The instrument timing and pointing of the electronic antenna can be programmed allowing numerous combinations. From the many technical possibilities four imaging modes have been designed to support a variety of applications ranging from medium resolution polarimetric imaging to high resolution mapping. Due to the short antenna the system is optimized for high azimuth resolution. Consequently, the pulse repetition frequency (PRF) must be high, which limits the maximum width of the swath.

The following imaging modes are defined for the generation of basic image products:

- StripMap mode (SM) in single or dual polarization
- High Resolution SpotLight mode (HS) in single or dual polarization
- Spotlight mode (SL) in single or dual polarization
- ScanSAR mode (SC) in single polarization

3.1 StripMap Mode (SM)

This is the basic SAR imaging mode as known from other radar satellites. The ground swath is illuminated with a continuous sequence of pulses while the antenna beam is pointed to a fixed angle in elevation and azimuth. This results in an image strip with constant image quality in azimuth. In **Figure 1** the StripMap mode geometry is illustrated. The characteristic parameters of this mode are listed in **Table 3**. The maximum length of an acquisition is limited by battery power, memory and thermal conditions in the sensor. The latter depend mainly on the PRF and on previous acquisitions.

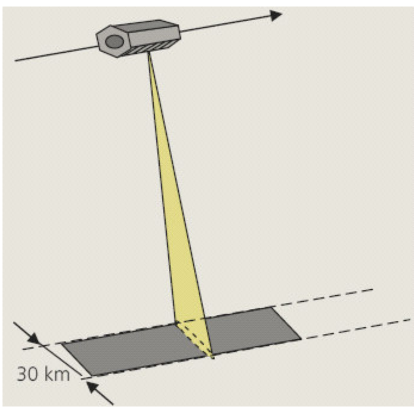

Figure 1: Imaging geometry in StripMap mode

Table 3: Characteristic parameters of StripMap mode

Parameter	Value
Scene Extension (azimuth)	50 km Standard Max. 1650 km
Swath width (ground range)	30 km (single polarization) 15 km (double polarization)
Data access incidence angle range	15°-60°
Full performance incidence angle range	20°- 45°
Number of elevation beams	ca. 27
Azimuth resolution	3 m at 150 and 300 MHz
Ground range resolution	1.55 – 3.21 m @ 45°-20° incidence angle
Polarization	Single pol (HH, VV), Dual pol (HH/VV, HH/HV, VV/VH)

As mentioned in **Tabl**e 3, StripMap can be operated in single or dual polarization mode resulting in one or two image layers, respectively.

3.2 SpotLight Modes

As depicted in **Figure 2**, spotlight mode uses electrical beam steering in azimuth direction to increase the illumination time, i.e. the size of the synthetic aperture. The larger aperture results in a higher azimuth resolution at the cost of azimuth scene size. In the extreme case of starring spotlight the antenna footprint would rest on the scene and the scene length corresponds to the length of the antenna footprint.

Two variants of the spotlight mode are designed with different values for azimuth resolution and scene size. For the product identification they are named “Spotlight” (SL) and “High Resolution SpotLight” (HS). Since SpotLight imaging takes only a few seconds and requires simultaneously a precise antenna steering as the sensor passes the scene, hitting the desired area of interest is not straightforward. The sensor technology offers high flexibility in order to image the user’s area of interest. In elevation, 123 spotlight elevation patterns are defined in order to adjust the scene center in small increments so that the required area can be placed in the middle of a scene. In azimuth about 125 beams from a set of 249 beams are used in one data take to extend the synthetic aperture. The imaging process is started GPS-controlled, i.e. when the satellite reaches a position along the orbit that is calculated from the user's required scene center coordinates. This way the effect of along track orbit prediction errors on the product location is compensated.

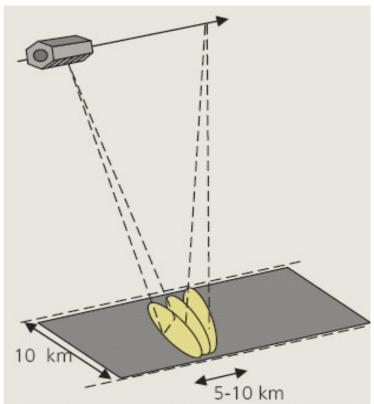

Figure 2: Imaging geometry in SpotLight mode

Table 4: Characteristic parameters of SpotLight mode

Parameter	Value
Scene extension (azimuth)	5 km SL 10 km HS
Swath width (ground range)	10 km
Data access incidence angle range	15°- 60°
Full performance incidence angle range	20° - 55°
Number of elevation beams	ca. 249
Azimuth resolution	1 m and 2 m (single pol) 2 m and 4 m (dual pol)
Ground range resolution	1.34m - 3.21m
Polarizations	Single pol (HH, VV); Dual pol (HH/VV)

3.3 ScanSAR Mode (SC)

In ScanSAR mode the electronic antenna elevation steering is used to switch after bursts of pulses between swathes with different incidence angles. In the designed TerraSAR-X ScanSAR mode, four StripMap beams are combined to achieve a 100 km wide swath. Due to the switching between the beams only bursts of SAR echoes are received, resulting in a reduced azimuth resolution. **Figure** 3 illustrates the ScanSAR imaging geometry. The ScanSAR swathes are composed exclusively from StripMap beams, i.e. they use the calibrated StripMap antenna patterns.

Similar to spotlight imaging, the start of a ScanSAR data take can be triggered by GPS when a predefined orbit location is reached. This feature allows repeated ScanSAR acquisitions with synchronized burst patterns which is a prerequisite for ScanSAR interferometry.

Table 5: Characteristic parameters of ScanSAR mode

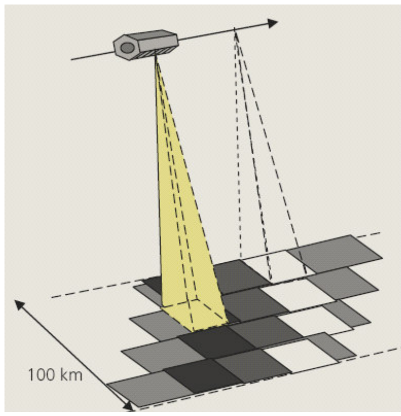

Figure 3: Imaging geometry in ScanSAR mode

Parameter	Value
Standard scene extension	150 km (azimuth) x 100 km (ground range)
Number of sub-swaths	4
Swath width (ground range)	100 km
Max. acquisition length	ca. 1650 km
Data access incidence angle range	15°-60°
Full performance incidence angle range	20° - 45°
Number of elevation beams	ca. 27
Azimuth resolution	16 m
Ground range resolution	1.55 m - 3.21 m @ 45°-20° incidence angle

4. TerraSAR-X Basic Image Products - Processing Level

All three modes of TerraSAR-X data will be available in four standard Level 1B image products, which can be selected depending on the desired application.

SSC: Single look Slant range Complex image is the basic single look product of the focused radar signal. The pixels are spaced equidistant in azimuth and in slant range, and the data are represented as complex numbers. Each image pixel is processed to zero Doppler coordinates, i.e. perpendicular to the flight track. This convention is compatible with the standard slant range products currently available. The SSC product provides the full bandwidth and the phase information, which is needed by applications like SAR interferometry and interferometric polarimetry.

MGD: Multilook Ground range Detected image is a detected multilook product where a simple polynomial slant to ground projection is performed in range using a WGS84 ellipsoid and an average, constant terrain height parameter. The image coordinates are oriented along flight direction and along ground range. The pixel spacing is equidistant in azimuth and in ground range. The advantage of this product is that an image rotation to a map coordinate system is not performed and interpolation artefacts are avoided. Consequently, the pixel localization accuracy is lower than in geocoded products. Only a coarse grid of coordinates is annotated in the product. The coordinates are calculated for an ellipsoid with an average elevation determined for the scene.

GEC: The Geocoded Ellipsoid Corrected image is referred to a map geometry using ellipsoidal corrections only (no terrain correction performed). This is a multi look detected product, projected and re-sampled to the WGS84 reference ellipsoid assuming one average terrain height. Available grid formats are UTM and UPS. As the ellipsoid correction does not consider a DEM, the pixel location accuracy varies due to the terrain.

EEC: The Enhanced Ellipsoid Corrected is an image referred to map geometry with terrain-correction using a digital elevation model (DEM). This is a multi look detected product projected and re-sampled to the WGS84 reference ellipsoid. The image distortions caused by varying terrain height are corrected using an external DEM. Available grid formats will be either UTM or UPS.

5. TerraSAR-X Enhanced Image Products

Orthorectified Image ORI^{SAR}: The enhanced ellipsoid corrected (EEC) SAR data, corresponding to DLR DEM standards, provides an excellent quality suitable for the vast majority of possible applications. On demand, high precision digital elevation models can serve as an improved input to the orthorectification process of the ORI^{SAR} images, resulting in a higher geometric accuracy. This is highly recommended for the SL mode.

Mosaic MC^{SAR}: Neighboring orthorectified images are combined into one, the intersection line being specifically selected in order to avoid the visibility of cutting edges.

Oriented Image OI^{SAR}: Oriented Images are subsets of a mosaic, which are characterized by sheet orientations according to relevant mapping standards or customer defined extensions.

Ascending-Descending Merge ADM^{SAR}: For certain applications, TerraSAR-X data may be better utilizable in a combination of ascending and descending scenes, reducing the impact of layovers and shadows in the image.

6. TerraSAR-X Applications

While Earth observation from space in the past was mainly focused on scientific or reconnaissance purposes, today data and derived information products are increasingly used for various commercial applications [2].

6.1 Basic Applications

Reconnaissance: The very high resolution and high radiometric accuracy; the weather and daylight independency; the flexible selection of modes, and the quick site access time of 2.5 days max. (2 days at 95% probability) to any point on Earth – thanks to its left-looking capability make TerraSAR-X the ideal sensor for such purposes. The result can be observed in **Figure 4**.

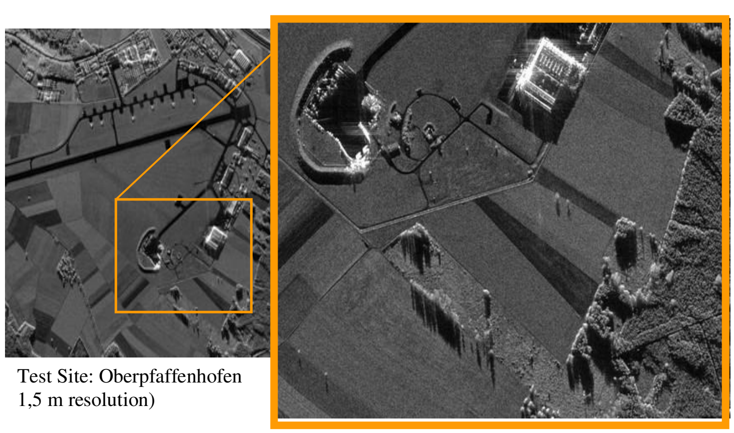

Figure 4: Example 1,5 meter resolution SAR Image

Topographic Base Maps: provide information about the Earth's surface on an artificial and natural level. Extracted linear, point, and spatial thematic features of TerraSAR-X data are a valuable input for topographic base mapping.

Land Use / Land Cover Maps: provide land surface information on different thematic levels. TerraSAR-X data delivers new input parameters that improve existing interpretation methodologies and thus the quality of land use and land cover maps [3].

As a compelemtary product, the future implementation of TanDEM-X – an additional spacecraft – would allow the generation of high-quality DEMs of any area on the globe.

7.2 Thematic Applications

TerraSAR-X data can contribute to an increased efficiency in the production of geoinformation products and sustainability of services.

Spatial Planning: TerraSAR-X supports the use of other EO data through its multiscale, multitemporal and multipolarized observations of remote areas that were formerly almost impossible to map. The backscatter intensity and textural information of the TerraSAR-X data provide information on the observed surface features.

Spatial planning, land use planning and especially monitoring of landscape changes require the survey of larger areas. Depending on the spatial planning level (community, district, province, state etc.), maps will vary in scale and information content. Not only the availability of sound topographic maps, but also an exact distinction of land use/land cover classes is the reliable basis for any further planning activities.

Earth Observation (EO) data is often employed for thematic mapping, but weather constraints like heavy rains, clouds, and reduced illumination often hinder a frequent enough observation of the investigation area. With the support of TerraSAR-X products and services, the current land cover and land use condition can be mapped more reliably and further exploited.

The combination of TerraSAR-X capabilities provides a unique setting to extract the following spatial information:

- Access to subtropical and tropical regions (cloud penetration)
- Map generation at various scales (different imaging modes)
- Detection of man-made features such as buildings, and metal surfaces like bridges, roofs, power lines, fences, wind energy parks, among others.

The polarization features can serve as additional information source on the observed surface. The content required for Spatial Planning can be derived from these features at different observation times and scales e.g. by statistical means.

The analysis will be visual interpretation, semi-automated or fully automated interpretation depending on the desired set of classes. It will mostly be based on the integrated analysis of TerraSAR-X data and other remote sensing data from previous observations or other satellite systems. Other ancillary information sources, including any existing map data may be used as well. Thus, TerraSAR-X band data is used complementarily to other sensors.

Risk Diagnostics: The weather independent TerraSAR-X data is an important basis for rapid mapping activities in case of natural disasters. Such maps significantly support crisis squads and helpers on the scene. In addition, they support insurance services as well as liability and reinsurance businesses. To be able to cope with increasing catastrophic events due to climate change, human influence, or earthquakes, a global overview of the affected area is necessary for quick and effective risk management.

With TerraSAR-X data, the following products can be generated: flood extension mapping, burned area mapping, and land subsidence monitoring.

These products are an essential input for further risk diagnostic products. The contribution of TerraSAR-X for risk diagnostic products will include activities such as:

- Estimation of the spatial and qualitative extent of damage caused by hazardous events to help with logistics planning
- Long term prediction and trend analysis of events
- Development and validation of mathematical models e.g. flood models
- Scenario generation to analyze estimated maximum loss based on data from previous events
- Input to site specific risk assessment like landslide and subsidence mapping
- Development of early warning systems to track the real time evolution of events to avoid or reduce damage

Forestry: TerraSAR-X will support overview forest mapping activities thanks to its relatively large swath, which facilitates large area assessments, but will also allow an assessment of small scale issues due to its high spatial resolution products.

Agriculture: TerraSAR-X supports agricultural mapping services through multitemporal and multipolarization observations and facilitates large area assessments. Agricultural applications can be generated from TerraSAR-X data and auxiliary data through synergistic exploitation and will be developed task-specifically.

8. Conclusions

TerraSAR-X data and services will be a major component in many applications related to geoinformation. In the Basic Applications, TerraSAR-X will contribute to Topographic Mapping, Digital Elevation Models and Land Cover / Land Use Mapping, which provide the core elements for any presentation or analysis of geographic information.

More specific applications are the Thematic Applications, which TerraSAR-X will support Agriculture, Forestry, Risk Diagnostics and Spatial Planning.

Depending on the information depth of the desired thematic map categories, the derivation from SAR data sometimes can get very complex. TerraSAR-X can support these actions through multitemporal and multipolarized observation facilitating a large area assessment.

TerraSAR-X supports the use of other EO data through its multiscale, multitemporal and multipolarized observations of remote areas that were formerly almost impossible to map.

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