TanDEM-X: Mission Overview and Status

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TanDEM-X (**T**erraSAR-X **a**dd-o**n** for **D**igital **E**levation **M**easurement) opens a new era in space borne radar remote sensing. A single-pass SAR-interferometer with adjustable baselines in across- and in along-track directions is formed by adding a second (TDX), almost identical spacecraft, to TerraSAR-X (TSX) and flying the two satellites in a closely controlled formation. With typical across-track baselines of 200-400m DEMs with 2m relative height accuracy at a 12 m posting will be generated. The HELIX concept provides a save solution for the close formation flight with vertical separation of the two satellites over the poles and adjustable horizontal baselines at the ascending/descending node crossings.

The TanDEM-X mission is implemented as a public private partnership (PPP) between the German Aerospace Centre and EADS Astrium GmbH. Representing the Federal Government of Germany, DLR will be the owner of the TanDEM-X data and coordinates their scientific utilisation. Infoterra GmbH a hundred percent subsidiary of EADS Astrium will exclusively distribute the TanDEM-X products to commercial customers. In return EADS Astrium contributes to the development cost of the satellite and will provide a sales-dependent share of the operating cost for the satellite.

Mission Products

The collection of scientific and commercial user requirements for the TanDEM-X mission clearly demonstrates the need of a highly accurate DEM data set with global access for both scientific and commercial users. The majority of the geo-science areas like hydrology, glaciology, forestry, geology, oceanography, and land environment require precise and up-to-date information about the Earth's surface and its topography. Digital topographic maps are also a prerequisite for reliable navigation, and the improvements in their precision needs to keep step with advances in the performance of global positioning systems. For commercial exploitation, DEMs and ortho-rectified images are the most important products for a growing Earth observation market.

Besides this primary goal of the mission, several secondary mission objectives are based on along-track interferometry or new techniques with bistatic SAR. From a comprehensive user survey, three standard data products have been derived: standard global DEM, DEM products on special user request with even higher height resolution or improved horizontal spacing and Radar Data Products acquired by along-track interferometry or new SAR techniques. For Radar Data Products the user has to provide specific data acquisition parameters like e.g. interferometric baselines and imaging geometry, SAR operation modes, instrument settings, etc. TanDEM-X will then acquire the desired SAR data during the available time slots.

The Joint Missions: TerraSAR-X & TanDEM-X

The missions TerraSAR-X and TanDEM-X will jointly share the same space segment consisting of the TSX and TDX satellites orbiting in close formation and will be operated using a common ground segment, being implemented by upgrading the running TerraSAR-X ground segment to a dual-mission ground infrastructure.

The TanDEM-X Spacecraft

The TDX satellite will be as much as possible a rebuild of TSX with only minor modifications. This guarantees a low development risk and it offers the possibility for a flexible share of operational functions for both the TerraSAR-X and TanDEM-X missions among the two satellites.

During the last phase of TerraSAR-X, the SAR design was extended to allow exchange of so-called Sync Pulses to support coherent operation of both SARs during bistatic operation. Six Sync Horns on each satellite provide a quasi-omnidirectional coverage. An additional propulsion system based on high-pressure Nitrogen gas is accommodated on TanDEM-X. This Cold Gas System provides smaller impulses than the Hydrazine system on both satellites (which is used for orbit maintenance) and supports formation flying by fine orbit control of the TanDEM-X satellite. An additional S-Band provides an Inter-Satellite Link and allows TanDEM-X to listen to the TerraSAR-X low rate telemetry and suppress radar transmission in case TerraSAR-X is in Safe Mode (which could mean a non-nominal orbit position and risk of illumination). The TanDEM-X Solid State Mass Memory capacity is 768Gbit which is doubled compared with TerraSAR-X to support the collection of the enormous amount of DEM data.

The TDX satellite will be designed for a nominal lifetime of 5 years and has a nominal overlap with TSX of 3 years. TSX holds consumables and resources for up to seven years of operation, allowing for a potential prolongation of the overlap and the TanDEM-X mission duration.

The HELIX Formation

The TanDEM-X mission concept is based on the coordinated operation of two spacecraft flying in close formation. Using two independent spacecraft provides the highly flexible and reconfigurable imaging geometry required for the different mission objectives. For example, the primary goal of generating a highly precise DEM requires variable cross-track baselines in the order of 200 to 500 m. In this close formation flight collision avoidance becomes a major issue and a minimum safety distance of 150 m perpendicular to the flight direction is to be observed around the orbit at any time. A formation, which fulfils these requirements, is the Helix formation.

The helix like relative movement of the satellites along the orbit is achieved by combination of an out-of-plane (horizontal) orbital displacement imposed by different ascending nodes with a radial (vertical) separation imposed by the combination of different eccentricities and arguments of perigee. Since the satellite orbits never cross the satellites can be arbitrarily shifted along their orbits. This enables a safe spacecraft operation without the necessity for autonomous control. Cross- and along-track baselines ranging from 200m to 10km and from 0 to several 100km, respectively, can be accurately adjusted. It is furthermore possible to optimize the along-track displacement at predefined latitudes for different applications.

TanDEM-X Operational Modes

The main parameters of the SAR sensor on TDX are fully compatible with those of TSX allowing not only independent operation from TSX in a mono-static mode, but also synchronized operation (e.g. in a bistatic mode). Operational DEM generation is planned to be performed using bistatic interferometry (Bistatic Mode), which is characterized by the illumination of a scene by one transmitter and the simultaneous measurement of the same scene with two receivers, thereby avoiding temporal variations of the ground surface characteristics, which would reduce the achievable height measurement performance.

The Radar Data Mode has been introduced as a synonym for the demonstration of innovative SAR modes and applications, offering a large variety of geometric constellations and of radar instrument settings. The instruments will be commanded according to the parameters selected by the scientists for Along-Track Interferometry (ATI) applications and for demonstration of new SAR techniques.

Close Formation Flight

Driven by the anticipated quality of the global DEM the two satellites have to be flown at distances between 200 and 500m. At such short distances special measures have to implemented in order to mitigate the risk of collision and mutual illumination by the main beams of the radar antenna. Beyond the additional Safe Mode based on use of the Magnet-Torquers the mission operations concept has been adapted to ensure timely reaction in case of space segment contingencies.

A given HELIX geometry will be kept fixed for one or more repeat cycle. The corresponding exclusion zones, i.e. orbit sections in which one satellite must not transmit radar pulses, are being calculated and used for on-ground checks of the timelines and command sequences as well as for an onboard exclusion zone logic. The synchronisation system provides for a bi-directional quasi communication link, which will be used by commanding dedicated sync warning data takes to trigger the onboard sync warning logic in case of poor receive signal levels indicating problems on the partner satellite.

Baseline Determination

The baseline describes the distance between the TSX and TDX for pre-defined geometrical reference points (phase centre of the SAR antenna) on the satellites and is an essential input for the interferometric processing. The baseline can be seen as a derivative of the Precise Orbit Determination for those satellites for which the baseline is needed. Precise Orbit Determination for the TSX and TDX satellites is based on the on-board GPS measurements taken by the two-frequency IGOR space receiver.

Mission Planning

A key issue in operating both missions jointly are the different acquisition scenarios: whereas TerraSAR-X requests are typically single scenes for individual scientific and commercial customers, the global DEM requires a global mapping strategy. Contrary to conventional Earth Observation missions, the TanDEM-X global mapping strategy has also to account for the formation geometry, as for given HELIX parameters, DEM acquisitions are only possible for a certain latitude range. The joint missions also have to share the limited space segment resources. A dedicated resource management has been designed to allow safe extended operations even beyond space segment specifications.

Ground Receiving Station Network

On top of Neustrelitz as the main TerraSAR-X ground station and additional commercial TerraSAR-X stations a dedicated TanDEM-X network of three X-Band ground stations (Kiruna in Sweden, Inuvik in Canada, and O'Higgins in Antarctica) is required to download more than 350 TeraByte of raw data for the global DEM. Upon successful reception at the receiving stations and a quick quality check the data will be written to tapes and shipped back for ingestion into the archive at the DFD.

Calibration and System Monitoring

Radiometric calibration of the TDX SAR instrument relies on the heritage from TSX and has been more than halved in duration. Prelaunch test results confirm this approach and support the expectation that TDX performs as well as TSX.

The DEM calibration concept foresees the adjustment of adjacent raw DEMs by means of a least-squares method and the use of accurate absolute height references to correct absolute offsets. Evaluation of swath overlaps and globally distributed accurate ground control points will allow correcting systematic height error trends. To support the least-squares adjustment and to provide good absolute height accuracy, globally distributed height references are needed. The ICESat space-borne Laser Altimeter has been selected as the source for providing ground control points with an absolute height accuracy of better than 1m.

A whole suite of monitoring and control facilities are foreseen to trigger immediate reaction in case of SAR instrument problems, failure of data recording and/or data dump to the receiving stations or in case of errors in the data driven parts of the processing chain.

Processing Chain

The entire processing chain is a new TanDEM-X specific development. However, it consists of individual modules which strongly benefit from the TerraSAR-X / TMSP and SRTM / InSAR heritage. Major design drivers result from the acquisition strategy which requires the combination of several (global) coverages and application of multi-baseline processing techniques which require supporting intermediate products. Another important constraint is the need for fast feedback on the data quality for acquisition (re-)scheduling despite the fact that joint acquisitions are downlinked over different stations and the arrival of the instrument data at the processing facility with a latency of up to several weeks.

The SAR data workflow of DEM acquisitions is thus subdivided in three major steps: screening of the downlinked data take segments at the receiving station, quality check and assessment of the collected screening results from a combined TanDEM-X acquisition at the processing facility and processing of the acquisition to scene based Raw DEMs upon availability of all necessary input data.

Finally, the DEM Mosaicking and Calibration Processor performs the production of a global digital elevation model from the incoming Raw DEMs. The absolute orientation of thousands of Raw DEMs is estimated and corrected by a continent wise block adjustment. Furthermore, the subsystem enables the fusion the Raw DEMs into a quality-controlled DEM that represents the final output.

In total the TanDEM-X mission data will fill 1,5 PetaByte in DFDs remote sensing data archive and the global DEM will amount to 15 TeraByte.