TanDEM-X Acquisition Planner

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Abstract

The TanDEM-X mission (TerraSAR-X add-on for Digital Elevation Measurement) consists of two almost identical satellites, TerraSAR-X (TSX) and TanDEM-X (TDX), launched in 2006 and 2010 respectively. They form a single-pass SAR interferometer with adjustable baselines in cross and along-track directions. The primary mission goal is to generate a global digital elevation model (DEM) with an unprecedented relative height accuracy of 2 meters at 12 meters posting. The flexibility of the formation flying system provides a configurable platform that allows carrying out secondary mission goals like local DEMs of even higher accuracy and along-track interferometry applications [1].

The mutual satellite lifetime of three years constraints the time to fullfil the TanDEM-X primary mission goal.

To achieve the mission requirements in terms of height resolution, the acquisition strategy has been divided into three phases. During the first and second phases, corresponding to the first and second years, two global Earth acquisitions (except Antarctica) are planned, each with a different height of ambiguity target. The difficult terrain will be scheduled to the third year.

This paper provides an overview of the TanDEM-X Acquisition Planner (TAP), an IOCS subsystem in charge of deriving the global DEM acquisition timeline for each phase, its corresponding radar parameters at datatake level, and the satellites formation. The global acquisition scenario and the target height of ambiguity are the TAP's main drivers.

1 Acquisition concept

Since the TanDEM-X and TerraSAR-X missions share the satellites resources, the datatakes of both missions are distributed homogeneously on both satellites. Furthermore, a Joint TerraSAR-X & TanDEM-X Acquisition Concept [2] has been elaborated to ensure that both mission goals are fulfilled successfully. According to this concept, the global DEM timeline is prepared well in advance.

The followed mapping strategy ensures that, with the chosen satellite formation, the height of ambiguity of the acquisitions is good enough to achieve the target height error that ensures a TanDEM-X DEM standard quality.

The acquisition strategy is furthermore constrained by the following factors:

- On-board mass memory: the storage capacity of TDX doubles the TSX one. Therefore TSX data is to be dumped always first.
- Ground station network and downlink capacity: the G/S network is limited and therefore, the storage capacity might reach its maximum during the peak load orbits.
- Data rate: In order to cope with the limited amount of memory storage, the amount of raw data might be reduced by adjusting parameters like the compression factor (BAQ), the PRF or the receiving bandwidth so long the performance of the acquisition is acceptable.
- Power and Thermal constraints: the possible orbit usage of each satellite varies with the length of the window. While it is restricted to 210 s in average per day it may increase to 400 s in one orbit.
- Access time: from the same orbit position several scenes can be acquired varying the elevation beam. This orbit position shall not be blocked for the same scene during adjacent repeat cycles.
- Long datatakes: The datatakes shall be as long as possible to ease the DEM calibration concept.

2 TanDEM-X Acquisition Planner

The TanDEM-X Acquisition Planner (TAP) is the IOCS subsystem that takes into account all these constraints and delivers the timeline and required data to command the TanDEM-X bistatic acquisitions, the so-called TAPTakes. The TAP subsystem is divided into four modules:

- TTG: TAP Timeline Generator
- APO: Acquisition Parameter Optimizer
- APC: Acquisition Parameter Calculator
- HEP: Height Error Predictor

In **Figure 1**, a diagram with an overview of the TAP modules is shown.

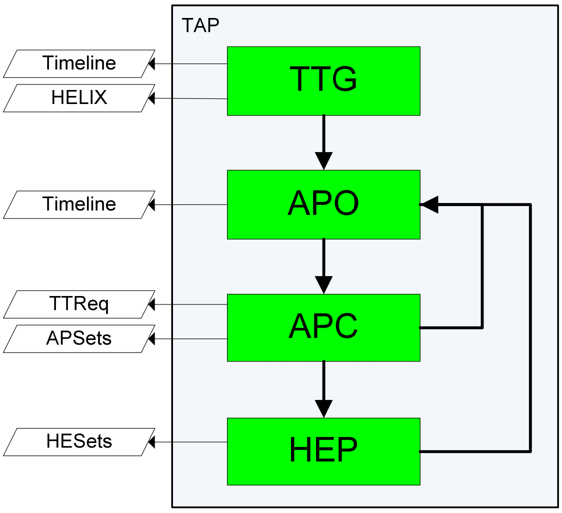

Figure 1 TAP modules diagram.

1.1 TAP-Timeline Generator (TTG)

The acquisition plan generation is started by the TTG module. To generate the timeline for the e.g. following four months of a mission phase the TTG retrieves as main inputs

- the landmasks to be acquired
- the elevation beam configuration
- target height of ambiguity

In TTG stage one it analyses the land area and evaluates which area has to be acquired from which orbit position and with which elevation beam. Now it is known when we need to record a ground area in reference orbit time using which beam.

In TTG stage two this information is converted into a feasible acquisition timeline in UTC time. This requires considering many additional hard and soft constraints. A hard constraint is a constraint which may not be violated at all like the power resource of the satellite. Soft constraints may be violated under special conditions. For example it is allowed to violate the minimum height of ambiguity in order to stop the acquisition at the ocean and thus not requiring an additional acquisition.

Example of constraints considered in the TTG are:

- power/thermal limits of the satellite
- downlink stations incl. their constraints (e.g. min elevation angle)
- satellite formation
- height of ambiguity
- minimum gap between datatakes
- possible datatake duration
- number of acquisitions at this orbit position
- acquisition started/stopped in the middle of to be acquired area

The calculation of the cross track and radial satellite baselines and their phase of librations is performed for each repeat cycle (11 days). The TTG starts the search of suitable formation parameters with a predetermined high cross-track baseline value. Each orbit second where the acquisition fulfils the Heigh of Ambiguity (HoA) requirements during the current repeat cycle is collected. Since the satellites baseline is shortened along the time, the HoA for the same beam increases. The HoA is derived as follows:

$$HoA = \frac{\lambda \cdot r_{Slant} \cdot \sin\theta_i}{B_{eff}}$$

According to the acquisition strategy, the satellites will get closer along each mission phase.

The scenes with highest HoA will therefore be considered prior to the other ones. Otherwise, as the baseline becomes smaller, they might not be possible to acquire due to the HoA allowed margins.

After the selection of the formation parameters the best acquisitions for smaller time periods (8 hours) are performed. For each time period all possible acquisitions are derived and then selected using a value function considering their constraints an performance.

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It is possible to generate TTG timelines for several landmasks given as input, each with its own height of ambiguity target: the global one and some additional areas. These additional areas are regions that might need to be acquired more than once with different conditions due to e.g., the insufficient quality reached in previous acquisitions.

The start and stop times, and the elevation beam for each TAPTake are then forwarded to the APO, who lengthens these times adding the margins needed by the instrument for the preparation of the datatakes (e.g., T/R modules warm-up). The flying formation parameters are the input for the generation of the TanDEM-X satellite's reference orbits.

1.2 Acquisition Parameters Calculator (APC)

The modified timeline is then sent on from the APO to the APC. Once the TAPTakes start and stop times and the elevation beam are known, the Acquisition Parameter Calculator provides, with the help of the SRTM DEM, a good approximation of the polygons on the Earth's surface that will be datataken. This information is recorded in the TAPTake Request (TTReq). This interface is the basis to derive the Acquisition Parameters Sets (APSets) for each satellite. These parameters are e.g., the echo window position and length, which are determined using the satellites position and the Earth's surface coordinates from the TAPTake Request; a suitable PRF; the receiver gain setting is determined with the help of a C-Band Backscatter map. Additional information found in the APSets concerning the active and passive satellites are the memory consumption, depending on the BAQ, PRF, receive bandwidth, and datatake time span; and the energy consumption, which depends on the duty cycle of the transmission pulse and the number of PRF commanded. The APC module is based on the TerraSAR-X mission module that computes the timing parameters [4] and has been extended for the bistatic case.

The APSets contain several proposals of acquisition parameters sets. This is done by considering different working conditions of the SAR instrument, such as different duty cycles, data compression factors (BAQ), receive bandwidths, PRF bands. In this way, several sets of acquisition parameters are available, each consuming different amount of memory and energy.

The APSets proposals are included to give the TAP the change to improve as much as possible the quality of the acquisitions. E.g., a higher duty cycle will transform in a higher SNR and, therefore, in a lower height error. The best option will be later in the chain selected by the Acquisition Parameter Optimizer, according to the available resources.

1.3 Height Error Predictor (HEP)

The HEP is fed with a TTReq and the correspondent APSets and gives back the estimated relative height error Δh for each single proposal, included in the input APSets. This new interface is the HESets.

For every orbit sample, the relative height error of 5 equidistant points in range is computed and written in the HESets. The Δh is evaluated as following:

$$\Delta h = \frac{HoA}{2\pi}\Delta\varphi$$

where $\Delta\varphi$ represents the interferometric phase error, derived from the knowledge of the total coherence γ_{tot}, as described in [1]. The total coherence represents a key-factor for the estimation of interferometric performance, and it depends on different contributions, such as limited SNR (γ_{SNR}), quantization (γ_{quant}), ambiguities (γ_{amb}), baseline estimation and co-registration errors (γ_{rg}), relative shifts of the Doppler spectra (γ_{az}), volume and temporal decorrelation (γ_{vol} and γ_{temp}). It evaluated as:

$$\gamma_{tot} = \gamma_{SNR} \cdot \gamma_{quant} \cdot \gamma_{amb} \cdot \gamma_{rg} \cdot \gamma_{az} \cdot \gamma_{vol} \cdot \gamma_{temp}$$

The impact of decorrelation sources varies depending on the input acquisition parameters and on the ground characteristics. For this second reason, a classification map, provided by ESA (reference: GLOBCOVER Products Description Manual, http://ionia1.esrin.esa.int/iages/GLOBCOVER_Prodct_Specification_v2.pdf), and a backscatter map for X-band [3] are taken into account, in order to achieve an high level of accuracy in performance estimation, not having to rely on theoretical reflectivity models only, but simulating close to reality scenarios.

Both the predicted height error Δh and the total coherence γ_{tot} are stored inside the output HEsets, as well as the single sources of decorrelation previously described.

1.4 Acquisition Parameters Optimizer (APO)

Once all the acquisition parameters and corresponding height error estimations for each proposal and for the whole timeline have been computed, the APO selects the best acquisition configuration of each TAPTake taking into account the height error and the available satellite resources.

The aim is to generate a timeline with an homogeneous and low height error.

The APO analyses all TAPTakes starting with the one having the largest height error. It checks whether a different acquisition setting, for example a higher pulse repetition frequency (PRF), is possible and provides a lower height error. If this is true it is verified that the different acquisition setting is feasible from satellite resource point of view. It is also considered that height error difference against the increased resources is balanced. For example an acquisition setting requiring the double amount of memory and reducing the height error by only 2cm would not be selected.

In result areas with low back scattering will be acquired with a normal PRF and a higher duty cycle while areas which are subject to high ambiguities will be recorded with higher PRF and normal duty cycle.

The final result of the APO is a TanDEM-X acquisition timeline with a low and homogeneous height error as far as possible using the available resources.

2 TAP results

Figure 2 shows the flight formation parameters derived for the first acquisition year and the estimated height of ambiguity for each TAPTake. After having analysed the first processed acquisitions, it was decided to increase the lower limit of the HoA from the

1st of April 2011 on in order to cope with the volume decorrelation over rain forest.

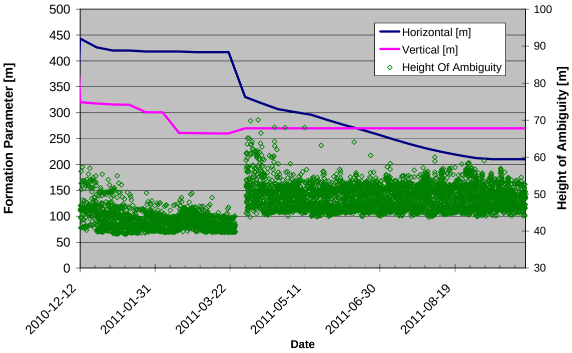

Figure 2 HELIX formation parameters and predicted height of ambiguity.

The total coherence is an indicator of the interferometric performance: the higher the coherence is, the lower is the height error.

A global coherence map of the processed TAPTakes is shown in **Figure 3.** According to the map, most of the acquisitions have high coherence values, fact that points out that the formation parameters have been successfully derived by the TAP.

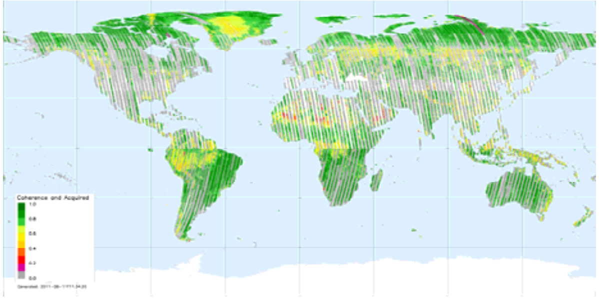

Figure 3 Global coherence map of the TAPTakes acquired between December 2010 and April 2011. The colour table goes from red (low coherence) to green (high coherence). The grey areas show acquired but not processed TAPTakes.

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