The TerraSAR-X Precise Orbit Control – Concept and Flight Results

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ABSTRACT

TerraSAR-X is Germany's first Earth observation synthetic aperture radar (SAR) satellite mission that carries an advanced high-frequency multimode SAR X-band sensor. The spacecraft was launched on the Russian DNEPR rocket on June 15, 2007 from Baikonur, Kazakhstan, and since then has been operated in a 514 km sun-synchronous dusk-dawn orbit with an 11-day repeat cycle.

Especially SAR interferometry drives the accuracy requirements for flight dynamics operations with respect to navigation and orbit control. In order to permit repeat-pass interferometry applications like subsidence mapping or glacier monitoring, the effective baseline between radar acquisitions in repeated orbits must not exceed 350 m. Hence, the TerraSAR-X osculating orbit is controlled with respect to an Earth-fixed reference track over the entire orbit, like a tube, with a deviation smaller than 250 m in the plane perpendicular to flight direction. This is very challenging, considering the low altitude with the highly dynamic disturbance forces acting on the satellite.

For the purpose of orbit monitoring and control we define a variable called space error, which is evaluated in the RTN orbital frame as the vector difference between the position of the real orbit (TSX) and the reference orbit (REF) at a time where the along-track component of the position difference is zero, e.g. at ascending node passage. The evolution of the normal space error mainly depends on the change of the orbital period due to atmospheric drag. This is illustrated in Fig. 1 for the evolution of the space error at ascending node passes within an ideal scenario with constant atmospheric drag. For a positive TSX-REF semi-major axis difference (i.e. R > 0), TSX is slightly slower than the reference. Because of the space error treatment in the Earth-fixed frame, this translates into positive increments of the normal space error at ascending node passes.

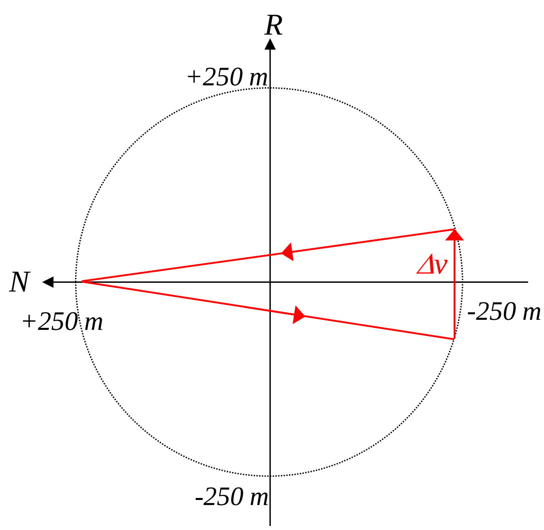

Figure 1. Ideal evolution of the space error at ascending nodes.

This space error drift is naturally reversed when the TSX-REF semi-major axis difference becomes negative. For our ideal scenario this happens in the middle of a maneuver cycle and exactly at the +250 m limit of the normal space error. When the space error reaches the right side of the 250 m tube, an orbit control maneuver is planned to raise the orbit and adjust the eccentricity. Due to density (and hence drag) prediction errors we experience both limit violations, i.e. N > +250 m when the real drag is smaller than the one considered in the maneuver planning, and too early drift returns, i.e. N < +250 m. Additionally, changes in the TSX-REF relative inclination, which are mainly caused by sun and moon third body perturbations, contribute to the normal space error at non-zero latitudes.

Within six years of TerraSAR-X operations more than 400 orbit control maneuvers have been performed. With increasing solar activity we experienced unpredicted strong variations in solar flux and geomagnetic activity, which significantly affected the predicted air density and hence the orbit decay. Consequences to the control performance and lessons learned will be addressed in the paper. The implemented reference orbit and orbit control concept have proved to work remarkably well. And, the tight control requirements are fully met even enabling the scientific and commercial users to detect millimeter-scale structural deformations of large buildings from repeat-pass interferometry. As an example, the control performance in the period of November and December 2009 is depicted in Fig. 2. The control accuracy achieved within the entire year 2009 is 19.5 m (rms) radial and 107.5 m (rms) normal space error.

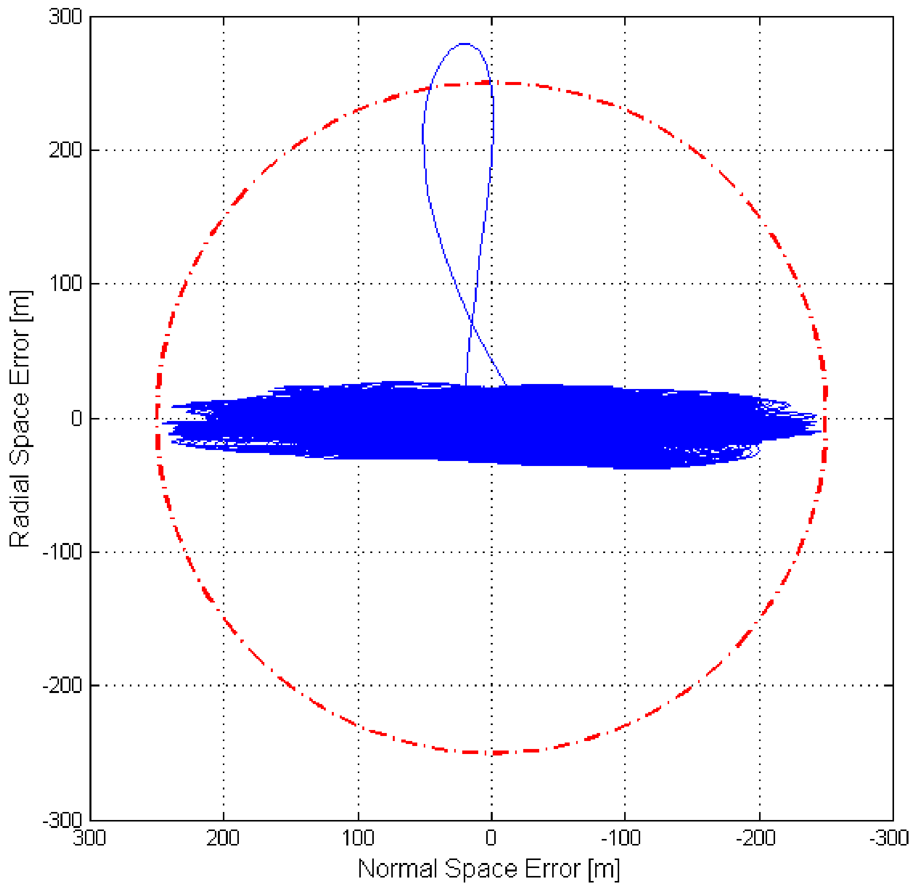

Figure 2. TSX orbit control performance in Nov.-Dec. 2009: radial vs. normal deviation of more than 900 orbits from the Reference Orbit. The dashed red line indicates the 250 m orbit control tube in the plane perpendicular to flight direction. The single orbit violating the upper radial limit resulted from a debris collision avoidance maneuver on 2009/11/27.