ORBIT PRECISION ANALYSIS OF SMALL MAN-MADE SPACE OBJECTS IN LEO BASED ON RADAR TRACKING MEASUREMENTS

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ABSTRACT

The growing number of space objects in the region near the Earth causes more and more concerns about the safety of LEO space missions. The so-called Kessler syndrome describes a scenario where the density of objects in LEO is high enough to cause a cascade of collisions between these objects. After the collision between Iridium 33 and Cosmos 2251 in 2009, many experts consider the cascade as started implying that the usability of the LEO region could be lost within the next 20 years. These future prospects could be avoided if at least five big pieces of space debris could be removed per year beginning in the near future. Besides the active removal of space debris, collision mitigation strategies have to be applied for active satellite missions.

The German Space Operations Center (GSOC) has been implementing a collision avoidance system since 2008. Bi-daily automated conjunction monitoring is carried out based on the USSTRATCOM catalog of Two Line Elements (TLE), but the decisions on collision avoidance maneuvers are mostly based on the Conjunction Summary Messages (CSM) released by the **J**oint **Sp**ace **O**perations **C**enter (JSpOC) in USA. Although JSpOC has direct access to the tracking data of the Space Surveillance Network (SSN), not all space objects are tracked with the same frequency and precision. Information about a critical close approach can sometimes have a degraded precision, particularly when combined with the lack of knowledge about the performed or planned maneuvers of an active satellite.

The safe approach and rendezvous in case of debris removal or the reliable estimation of the collision risk in case of a critical close approach both require the orbit of the space debris to be known as precisely as possible. The precise estimation of the orbital elements of the space debris object, or a refinement with respect to the publicly available TLE catalog, can be achieved using measurements from a dedicated radar tracking campaign.

This study investigates the precision with which the orbit of a small object that can be determined and propagated based on radar tracking measurements. The Tracking and Imaging

Radar (TIRA) of Fraunhofer FHR in Wachtberg, Germany, was used to track the Canadian nanosatellite CanX-2 over a period of five days. CanX-2 is a triple CubeSat of the size 10x10x30 (cm) carrying a dual frequency GPS receiver, and orbiting the Earth in a Sun-synchronous polar orbit with a 635km altitude and a 9:30 am descending node. Due to the nanosatellite's power and downlink constraints the GPS receiver was only operated for approximately 90 minutes twice daily. The GPS on-time was coordinated with the visibility of CanX-2 for TIRA. The precise orbit generated with CanX-2's GPS data is used as a reference for the radar measurement results.

The first part of the paper discusses the CanX-2 orbit and satellite features and elaborates on the campaign performed in February 2012. In particular, the radar tracking and GPS operations timeline are presented.

Next, the calculation and validation of the reference trajectory is discussed. Precise orbit determination (POD) is performed based on dual frequency GPS carrier phase and pseudorange measurements. The degraded POD accuracy for the periods outside GPS receiver operations, up to 12 hours, is quantified by means of a similar analysis with TerraSAR-X precise orbits. The estimated accuracy of the CanX-2 reference orbit is on the 1-m level during GPS observation arcs, and up to 10 m during typical GPS outages of up to 12 hours.

Furthermore, statistics of orbit determination precision using different measurement data arc lengths for the radar tracking as well as for the onboard GPS navigation solutions are presented. The accuracy of an orbit prediction over a period of up to 3 days is analyzed as well. In both cases, orbit determination and propagation, the orbit ephemeris is compared with the POD reference trajectory. For example, for a radar tracking scenario comprising of 6 passes within a 36 hours period a remarkable orbit determination accuracy of 10 m in radial / normal direction (1D, RMS) and an accuracy of less than 60 m (RMS) in the along-track direction is computed from comparison to the reference orbit. After 3 days of orbit propagation a corresponding maximum position error of only 100 m (3D, RMS) is found. Of course, both orbit determination and propagation accuracies are significantly degraded in case of shorter observation arcs and less tracking passes.

The outcome of this paper is a better understanding of the prediction uncertainty of a critical close approach between an active satellite and a small object, as well as an understanding of the necessary effort required to refine the orbit of a space debris object for safe space debris removal.