Space Emitter Orbit Refinement Using RF Signal Measurements from Multiple Space Assets

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I. Introduction

Due to the increasing number of space objects from around the globe, it is more important than ever to better solve the Space Domain Awareness (SDA) problem to plan maneuvers and trajectories that avoid collisions of resident space objects (RSO). In January of 2007, the Chinese shot an old weather satellite of theirs with a missile, causing the largest man-made cloud of space debris in our history. In 2008, the US destroyed a reconnaissance satellite that had failed but was done at a low enough altitude that atmospheric drag prevented the debris from remaining in a long term orbit. An accidental collision happened in February 2009, when a communications satellite and an old unused Russian satellite collided. This unfortunate accident happened at an altitude that will cause the debris to stay in Earth's orbit for a long time [1].

Improving RSO tracking is not only important to prevent collisions with space debris and other RSOs, it is also important for increased capability and reliability of space assets to perform their missions. For these reasons, RSO tracking is of the utmost importance for space asset protection and effectiveness.

Traditional strategies for RSO tracking typically involve ground-based techniques such as optically tracking RSOs using telescopes. The Ground-based Electro-Optical Deep Space Surveillance (GEODSS) system owned by the U.S. is one example of this. The GEODSS consists of three separate telescopes to track RSOs in various orbits around the Earth [1], [2], [3]. Ground-based radar systems are also used to help catalog and track RSOs [1], [4].

Spaced-based RSO tracking techniques have also been used, such as an optical sensor aboard a satellite. An example of this is the Space Based Visible (SBV) sensor on the Midcourse Space Experiment satellite, which helped to improve ground-based tracking estimates [2], [5]. SBV is no longer in operation and the Space Based Space Surveillance (SBSS) satellite acts as a replacement [2]. Using space-based optical measurements for RSO tracking has been a popular topic of research [2], [3], [5], [6].

Andrews and Geller [3] combined the information from ground-based and space-based optical measurements to better estimate the state of an uncooperative Geosynchronous Equatorial Orbit (GEO) satellite. They assumed the space-based measurements provided angle only measurements and that the chaser satellite was in a near-GEO orbit. Their work focused on developing an efficient tool based on linear covariance theory to improve the state estimate of the uncooperative GEO satellite in this setup.

Segal, et. al. [6] also attempt to solve the tracking problem of an uncooperative satellite or space object. Their problem involves using a chaser satellite equipped with a stereo vision sensor (2 cameras) to track the target with little or no a priori information about the target. Due to this, they focus on developing the estimation scheme for this sensor in this setup. Their estimation scheme uses multiple iterated extended Kalman filters (IEKFs) and an inertia tensor identification algorithm. Their approach is similar to a multiple model Kalman filter technique.

Li, et. al. [5] focus on tracking low Earth orbit (LEO) space debris using optical measurements from two space-based sensors. Their work discusses optimizing the formation of the space-based sensors, along with using the sensor in a scanning mode as opposed to a tracking mode, which requires less attitude maneuvers of the optical sensor/satellite.

Other ground-based and space-based tracking techniques use measurements from radio frequency (RF) signals [4], [7], [8]. These measurements typically come from time-difference-of-arrival (TDOA), angle-of-arrival (AOA), and/or frequency-difference-of-arrival (FDOA) of the receivers.

Benson [7] uses a unique approach. He investigates the feasibility of tracking space debris by using the low-power scattering of radio signals from Global Navigational Satellite System (GNSS) satellites with ground-based receivers. This effectively uses GPS signals as a form of bistatic radar. A benefit of this approach is that it uses pre-existing GNSS signals that are well defined and timed, with the drawback of having a very low power signal. The work analyzes the performance and budget necessary to implement this strategy.

Shuster, et. al. [8] use TDOA measurements from multiple space-based receivers to determine the initial orbit of the RF emitting RSO. One of the benefits of using the TDOA measurement, is that it requires little previous knowledge about the emitted RF signal, allowing it to be used on an uncooperative satellite. Using TDOA requires multiple measurements over time, depending on the number of space-based receivers, to determine the orbit of the target satellite. This work assumes the space-based receiver orbits are known.

The present work proposes to study the RSO tracking problem using a space-to-space approach similar to Shuster, et al. [8]. Specifically, the target RSO emits a RF signal that multiple space-based receivers can detect, giving various AOA and TDOA measurements. An extended Kalman filter (EKF) can leverage the AOA and TDOA measurements to refine the orbital state estimate of the emitter RSO. This work will also study the sensitivity of the emitter's orbital covariance with respect to the number of space-based receivers and their respective orbits (radius, inclination, etc.).

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