Acta Astronautica 112 (2015) 56–68

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

An approach to ground based space surveillance of geostationary on-orbit servicing operations

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ARTICLE INFO

Article history:
Received 5 November 2014
Received in revised form
5 February 2015
Accepted 7 March 2015
Available online 18 March 2015

Keywords:
Satellite tracking
Space surveillance
Space situational awareness
On-orbit servicing
Differential angles tracking

ABSTRACT

On Orbit Servicing (OOS) is a class of dual-use robotic space missions that could potentially extend the life of orbiting satellites by fuel replenishment, repair, inspection, orbital maintenance or satellite repurposing, and possibly reduce the rate of space debris generation. OOS performed in geostationary orbit poses a unique challenge for the optical space surveillance community. Both satellites would be performing proximity operations in tight formation flight with separations less than 500 m making atmospheric seeing (turbulence) a challenge to resolving a geostationary satellite pair when viewed from the ground. The two objects would appear merged in an image as the resolving power of the telescope and detector, coupled with atmospheric seeing, limits the ability to resolve the two objects. This poses an issue for obtaining orbital data for conjunction flight safety or, in matters pertaining to space security, inferring the intent and trajectory of an unexpected object perched very close to one's satellite asset on orbit. In order to overcome this problem speckle interferometry using a cross spectrum approach is examined as a means to optically resolve the client and servicer's relative positions to enable a means to perform relative orbit determination of the two spacecraft. This paper explores cases where client and servicing satellites are in unforced relative motion flight and examines the observability of the objects. Tools are described that exploit cross-spectrum speckle interferometry to (1) determine the presence of a secondary in the vicinity of the client satellite and (2) estimate the servicing satellite's motion relative to the client. Experimental observations performed with the Mont Mégantic 1.6 m telescope on co-located geostationary satellites (acting as OOS proxy objects) are described. Apparent angular separations between Anik G1 and Anik F1R from 5 to 1 arcsec were observed as the two satellites appeared to graze one another. Data reduction using differential angular measurements derived from speckle images collected by the 1.6 m telescope produced relative orbit estimates with better than 90 m accuracy in the cross-track and in-track directions but exhibited highly variable behavior in the radial component from 50 to 1800 m. Simulations of synthetic tracking data indicated that the radial component requires approximately six hours of tracking data for an Extended Kalman Filter to converge on an relative orbit estimate with less than 100 m overall uncertainty. The cross-spectrum approach takes advantage of the Fast Fourier Transform (FFT) permitting near real-time estimation of the relative orbit of the two satellites. This also enables the use of relatively larger detector arrays ($> 10^6$ pixels) helping to ease acquisition process to acquire optical angular data.

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http://dx.doi.org/10.1016/j.actaastro.2015.03.010

1. Introduction

On Orbit Servicing (OOS) is the on-orbit delivery of interventional services to spacecraft. On Orbit Servicing encompasses a broad area of mission types including satellite rendezvous, inspection, captivation, repair, consumables replenishment (such as fuel or cryogens), orbital adjustment/deorbit and possibly the on-orbit construction of or reuse of large, complex space structures.

On Orbit Servicing has historically been performed by the manned spaceflight community on Space Shuttle [1], and International Space Station programs [2]. Subsequently, autonomous systems have recently begun to show technical viability in this space mission class. The Japanese ETS-VII mission [3] demonstrated tele-robotic captivation of a small capture article in 1997. The XSS-series [4] of small satellite missions demonstrated autonomous formation flight with an aim to test servicing technologies. Robotic satellite refueling experiments aboard the International Space Station (ISS) [5] are currently being performed with a view toward testing procedures needed for robotic servicing of satellites in geostationary orbit.

The success of the Orbital Express technology demonstration [6] (2007) exemplified the viability of autonomous, robotic, satellite to satellite OOS. Several key space-based mission milestones were achieved without operator intervention including autonomous rendezvous and captivation, hydrazine refueling, battery and electronics replacement.

Subsequent to the Orbital Express mission some industrial proposals [7,8] for geostationary satellite refueling were socialized but were not fully financed. The current DARPA Phoenix [9] mission intends to demonstrate derelict satellite re-use by severing antenna dishes from a geosynchronous satellite and affixing them to a smaller electronics package. This is a complex and challenging orbital construction activity.

While autonomous OOS space missions are yet to be routinely flown it appears that technical maturity has been achieved by several nations and makes it likely that this capability will be fielded in the near future. A future capability to remotely observe OOS activities prior to an object's captivation would be of value to the space surveillance community.

1.1. The space surveillance problem and OOS

While OOS space mission types are yet to become a regular part of the space mission activity, the Space Situational Awareness (SSA) community may be impacted in its ability to track and detect OOS activities occurring in deep space (e.g. geostationary orbit). Space surveillance of deep space orbits (such as geosynchronous orbit) is usually performed with sensitive, wide field, visible-light optical telescopes designed to collect angular measurements and later invoke an orbit determination process to update the orbital catalog. In order to detect small, faint objects in deep space, wide-field images collect large swathes of sky in a single frame collecting both resident space object and background stars. Relatively large pixel scales (~2–~6 arcsec) are used to increase the probability of detection of an Earth orbiting object and background stars to enable astrometric position measurement. (See Fig. 1).

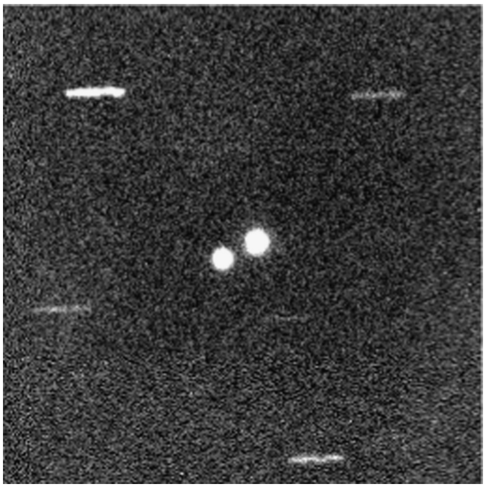

Fig. 1. Satellites (point sources) Anik F1 (lower left) and Anik F1R with background stars. Image credit: DRDC Ottawa Research Center.

This approach works well for deep space objects as long as the objects have angular separations larger than a few arcminutes. The typical apparent angular separation between objects in geostationary orbit is $\sim 0.1^\circ$ which is the typical longitude slot width assigned to operational geostationary satellites. Some geostationary operators periodically locate two or more satellites within one slot which tends to force satellites to have angular separations less than 0.05° or less (geostationary satellite co-location). The apparent angular separation is dependent on observer location [10].

An OOS mission would be unobservable to these space surveillance systems as they would be unable to resolve the OOS satellite pairs as their separations are an order of magnitude less than typical in geostationary orbit. The relative distance between the two objects in OOS proximity flight is generally less than 500 m (~2.5 arcsec as observed from Earth's surface). Some key impediments prevent OOS activities from being detected; (1) the inherent point spread function of the optics and pixel pitch of the detector array of the telescope and (2) the seeing (turbulence) of Earth's atmosphere. Detectors are only able to resolve the angular information proportional to the size of the pixels and the aperture diameter of telescope, however this can be addressed via good engineering and design. The turbulence-induced "seeing" of Earth's atmosphere is approximately 1–2 arcsec (at good astronomical sites) which masks activity which one wishes to observe. At geostationary satellite slant ranges atmospheric seeing scintillates a satellite pair with an effective size of approximately 200–400 m linear distance. If two satellites performing OOS operations are in relative motion closer than the angular size of the atmospheric seeing disk, the atmosphere blurs the position of the satellites together as viewed by the observer (Fig. 2).

OOS missions in geostationary orbit could create new operational issues for SSA operators when the OOS pair have separations less than 500 m. Close proximity