

Multi-Static Radar for Manoeuvre Detection ^{*}

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Abstract. Since their inception, ground based space situational awareness (SSA) systems, also known as Space Surveillance and Tracking (SST), primarily have utilised radar sensors due to their ability to operate in very long ranges and under various atmospheric conditions while also providing very accurate range measurements. Initially used for early missile warning, modern SST radars are designed to monitor targets in Low Earth Orbit (LEO) up to deep space. Having very high power transmissions, in order to improve their efficiency, radar can also operate in tandem with a nearby radio telescope, forming what is known as a bistatic configuration. In this configuration, the reflected signal is received not only by the primary emitter station, but also by distant RF telescopes.

A prime example of such bistatic system is the Tracking and Imaging Radar (TIRA) located at Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR), Germany and the Effelsberg radio telescope which when paired can improve the minimum detectable target size from 2cm at 1000 km down to 1cm due to the higher sensitivity of Effelsberg. While being technically bistatic, it acts more as a quasi-monostatic radar due to the very high target altitudes. The experienced bistatic angles, β_{BS} , are generally small and the perceived radar cross section (RCS) of the target will be very similar to that of a monostatic radar. Recently, the use of long baseline bistatic radar systems for SST has been investigated within the NATO SET-293 RTG ¹. The difference with existing bistatic systems is that the RF telescopes are remotely located from the radar allowing larger bistatic angles and essentially viewing the target from different aspect angles. Specifically, capturing the target reflection in different bistatic angles can result in a higher RCS than the monostatic depending on its shape. In addition, the radar system could integrate multiple receiving signals, i.e from multiple transmitters or using multiple receivers, resulting in a higher signal to noise ratio (SNR). Moreover, combining location and velocity estimates of a target from distributed sensors can significantly improve the parameter estimation accuracy.

While preliminary analysis on captures of GEO satellites has shown that spaceborne targets can be detected in these bistatic configurations, covered research lacks from a more extensive investigation of the bespoke

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¹ <https://www.sto.nato.int/Lists/test1/activitydetails.aspx?ID=16824>

processing framework and performance analysis aimed at fully unlocking the benefits of such a system.

The use of tracking data from radar systems allows the reconstruction of the motion of space objects beyond the simple orbit determination. If one assumes that the object in view has a behaviour dictated by an unknown part of the dynamics, it is possible to use modern machine learning techniques to reconstruct the missing part of the dynamics and recognise patterns or intentions. This process is called behaviour analysis. In this work we assess the benefits and trade-offs of multiple behaviour analysis methods proposed in the literature, which we apply to this use-case of spacecraft being observed by bistatic or multistatic radar. We then investigate to what extent the increased data quality coming from bistatic radar observations improves the accuracy of the results of the behaviour analysis process when compared to the monostatic case. We look at optimal control and statistics based metrics. In general, they provide a metric that measures the likelihood that a manoeuvre was performed, and/or a mathematical description of this manoeuvre.

We consider in particular two possible scenarios: a repositioning to modify its ground track, and an orbit re-positioning to shadow another satellite. These two case studies will be used to assess the scenarios for which manoeuvre detection is more accurate with bistatic only radar than monostatic radar.

To summarize, we expect to obtain concrete information on the benefits of using a bistatic setup compared to a monostatic one for the purposes of behavioural analysis when applied to realistic scenarios.

Keywords: Multi-static radar, bistatic radar, manoeuvre detection, space surveillance and tracking