Passive radar for launch and re-entry support

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ABSTRACT

In December 2021, Silentium Defence opened the 'Oculus' observatory hosting the MAVERICK OmniGuard radar - the first purpose-built space situational awareness (SSA) sensor utilising passive radar technology. Silentium has been operating this radar in a *cued* mode to provide catalogue update information - observations and elsets - to customers since that time. In this paper we give an overview of recent updates to the Silentium OmniGuard radar allowing it to produce near real-time *un-cued* observations on resident space objects (RSO). This un-cued mode does not require any prior information about the position of an object and hence allows the detection of un-catalogued RSOs or those that have shifted significantly from earlier orbits. Combining the instantaneous wide field-of-view afforded by passive radar with this un-cued capability unlocks the ability to use passive radar for launch and re-entry surveillance.

1. PASSIVE RADARS FOR LEO SSA

Passive radars, unlike traditional radars, utilise radio frequency (RF) energy already in the environment to obtain radar detections. The transmitter exploited in a passive radar system is typically non-cooperative and can be located at a considerable distance from the receiver. A representation of a passive radar system for space surveillance is shown in Fig. 1. Energy from the transmitter propagates along the paths shown in red, illuminating numerous resident space objects (RSO) over a broad angular extent. The reflected RF energy from these RSOs, shown in white, is then received by the passive radar surveillance array. This places the passive radar into a bistatic configuration and requires the passive radar system obtain a reference copy of the transmitted signal for processing.

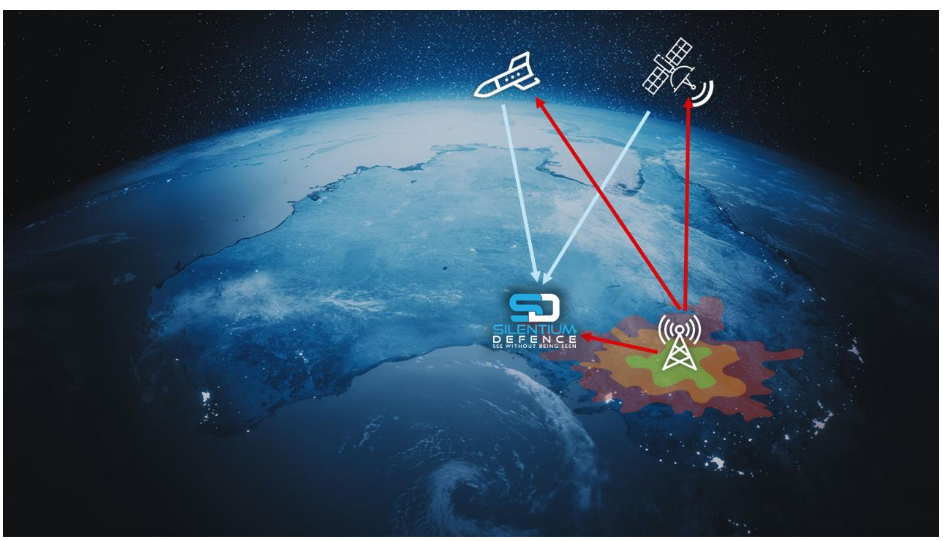

Fig. 1. Passive radar concept

The surveillance array will typically be comprised of many individual antenna elements, with the collected energy being conditioned and digitised independently. This allows simultaneous receive beams to be formed during the processing stage with the reference signal.

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The MAVERICK OmniGuard at Oculus exploits FM radio broadcasts transmitted from multiple sites across south-eastern Australia as shown in Fig. 2. Located up to 400 km from the observatory, these broadcast sites collectively transmit several megawatts of continuously radiated power across the field of regard. This abundance of existing energy from geographically diverse sources, and the ability to form simultaneous beams, enables persistent wide field of view coverage.

Fig. 2. The location of the MAVERICK OmniGuard and high power transmit sites in South Australia and Victoria, Australia exploited for SSA observations

The native measurement space for a passive radar is frequency difference of arrival (FDOA), time difference of arrival (TDOA), and 2D angle. This measurement space allows relative position and velocity to be calculated on each measurement frame. The measurement capabilities of the OmniGuard radar have previously been reported at AMOS [1]. Passive radars can also operate continuously, regardless of the time of day or most weather conditions, allowing observations to be conducted largely uninterrupted.

It is these capabilities that make passive radar well suited to launch detection, supporting launch and early orbit phase (LEOP) activities, and monitoring for object re-entry. Safe and efficient launch operations require launch collision avoidance (LCOLA) assessments to be timely, reliable, and based on frequently updated space situational awareness (SSA) data. The continued growth of RSOs in low earth orbit (LEO) makes the collection of timely SSA data for this assessment a formidable operation. Further, cued SSA sensor operation can be a limitation when the ephemeris of the targeted RSO is not sufficiently known, such as following a significant manoeuvre or RSO re-entry.

2. CUED RADAR OPERATIONS

The increase in the number of RSOs in LEO, driven by the rapid expansion of mega-constellations such as SpaceX Starlinks [2], has driven a need for low cost, high capacity SSA sensors for reliable space traffic management. Worldwide, various active and passive sensors have been utilised for SSA such as LeoLabs' phased array active radars network, the Australian Defence Science and Technology Group (DSTG) experimental high frequency (HF) line-of-sight (LOS) radar system [3], the Murchison Widefield radio astronomy array (MWA) [4] and Silentium Defence OmniGuard passive radar.

Silentium Defence has shown the value of a cued passive radar for SSA operations. A key advantage of passive radar over a traditional pulsed-Doppler radar is that the latter transmits bursts of energy over a narrow sector, compared to the continuous illumination over a very broad area that passive radar can utilise. Passive radar can thus,

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without interruption, simultaneously track many RSOs across a very wide field of regard. An example of this is given in Fig. 3, which shows detections on 6 RSOs simultaneously over an approximate ground area of 200,000 km^2.

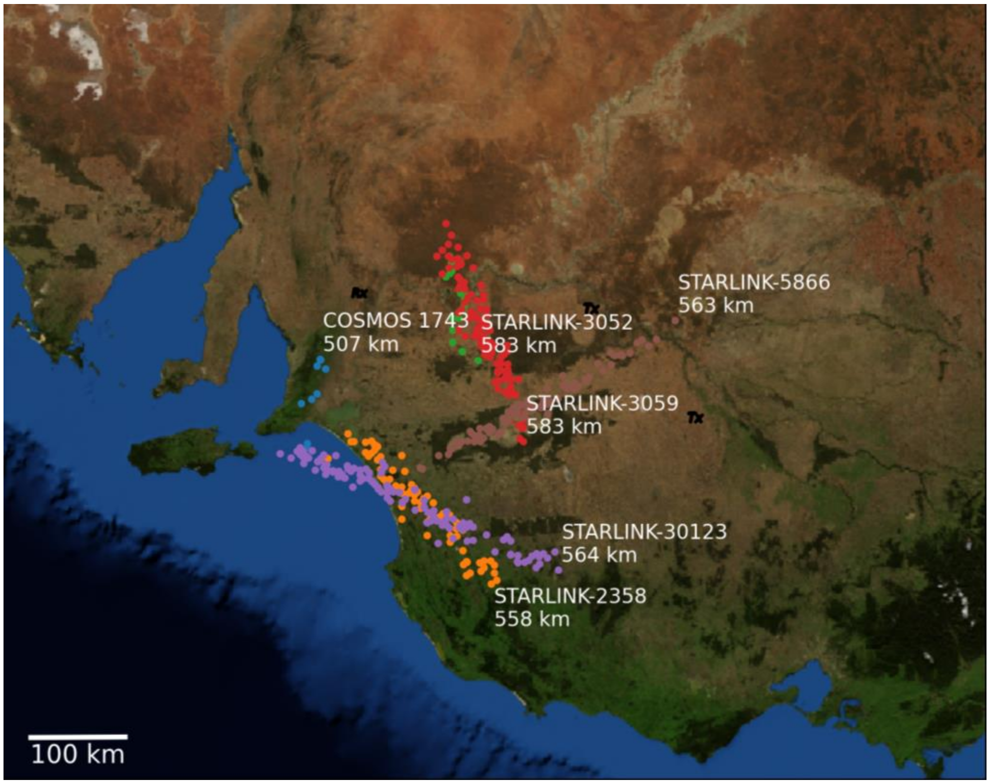

Fig. 3. Simultaneous detection and tracking of 6 RSOs using the OmniGuard radar in cued mode

Passive radar employs signal processing and beamforming techniques that enable coherent processing intervals (CPI) of the order of several seconds to be achieved. This integration period is selected to strike a balance between the target's relative motion, and the energy required to achieve a sufficient signal-to-noise ratio (SNR) for detection. A cued radar system relies on prior information to provide the spatial and motion information to limit the search region for acquisition of a RSO of interest. This is because for fast moving and accelerating targets like RSOs, the radar returns will likely suffer from range and Doppler migration issues. Using the cued information, one can refocus the energy caused by the range, Doppler, and angle migrations.

A system with sufficient prior information is thus capable of maximising the SNR and probability of detection of an RSO. In a dynamic environment such as space, small perturbations to the drag coefficient, due to space weather for example, or the limitations of the propagated elset result in RSO location and motion varying from the cued information. This variation may result in the SNR being lower than anticipated or detection opportunity being missed altogether. To compensate for this, the OmniGuard radar performs a constrained search around the cueing information, allowing it to detect RSOs within defined uncertainty bounds. Larger variations however from this cueing information - for example resulting from a manoeuvre, re-entry, or other space event – will often lead to a missed detection opportunity. This missed detection itself contains information, informing the system that cueing elset may be invalid; however additional processing must now be performed to reacquire the RSO. Further, a recent launch will likely either have no available cueing information or a launch nominal that is insufficient to cue from.

3. UN-CUED PROCESSING CAPABILITY

To address the limitations of a cued system, Silentium Defence has recently developed a fully un-cued processing capability for SSA. Further, this processing approach implemented by Silentium Defence engineers simultaneously reduced the latency of the radar, increased the track capacity, and allowed the MAVERICK OmniGuard to provide situational awareness in both air and space modes concurrently. Since this processing operates completely independent of the cued information, it unlocks the potential of passive radar for application in launch and re-entry support.

Fig. 4 illustrates un-cued detections across a 10-minute interval on August 24, 2024 exploiting a single FM radio station. The y-axis represents the bistatic range whilst the x-axis is presented in UTC time. The detections have been run through an automatic association algorithm to correlate with publicly published elsets from space-track. This association utilises the full measurement dimensions of passive radar – bistatic delay (presented as bistatic range in this figure), bistatic Doppler, and 2D angle.

Detections shown as black dots in Fig 4. are those where the association was absent; this may be false detections, potentially due to interference in the waveform, as shown at ~00:10, or could be a valid detections on a manoeuvred or un-catalogued RSO (possible example at ~00:16). Detections shown as green crosses in this figure are those that were successfully associated – the curves in blue show the bistatic delay of the associated RSO derived from the public elset.

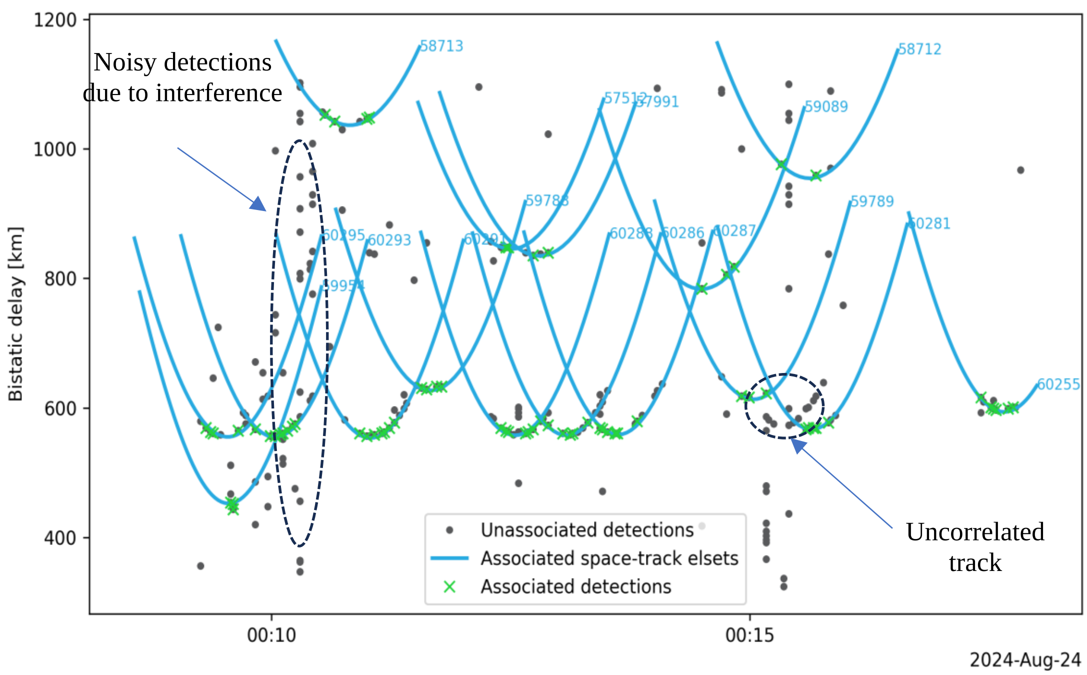

Fig. 4. Un-cued detections from the OmniGuard radar plotted as bistatic delay vs UTC time. Detections marked as green crosses were associated with space-track elsets, and un-associated detections as black dots.

This example 10-minute window includes detections on 17 RSOs – 16 of which were associated with catalogued objects. This is a 6-fold increase in the typical operational capacity of the cued processing mode currently utilised on the OmniGuard radar. This already significant increase does not represent the maximum processing capacity of the un-cued mode, with further increases expected as more transmitters are exploited and sensitivity is further increased.

This processing technique has also been shown to be significantly faster than the cued technique – bringing latency down to the order of 5 minutes.

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4. INITIAL ORBIT DETERMINATION

In SSA applications where an uncorrelated track (UCT) is observed, such as new launches, it is highly valuable to be able to produce a reliable initial orbit determination (IOD) from the data. To demonstrate this capability, a pass of the International Space Station (ISS) was used as a surrogate for a newly launch object. This pass was selected as it occurred immediately after a manoeuvre of the ISS but before an updated elset was publicly published.

An IOD technique, tailored for the bistatic nature of passive radar and tuned to exploit the fine native Doppler resolution, was developed with Australian company InTrack Solutions. This IOD technique has been applied to the un-cued detections of the ISS to generate an elset; the un-cued detections and resultant orbit are shown in Fig. 5. In this figure, green crosses are the detections accepted by the IOD processing, while the black trace is the resultant orbit. This orbit has then been compared to the pre-manoeuvre and post-manoeuvre elsets published by space-track, shown as dotted dark blue and light blue lines, respectively. It can be observed that the generated elsets are in good agreement[1] in both bistatic delay and Doppler with the post-manoeuvre elsets that were published by space-track 4 hours after the pass.

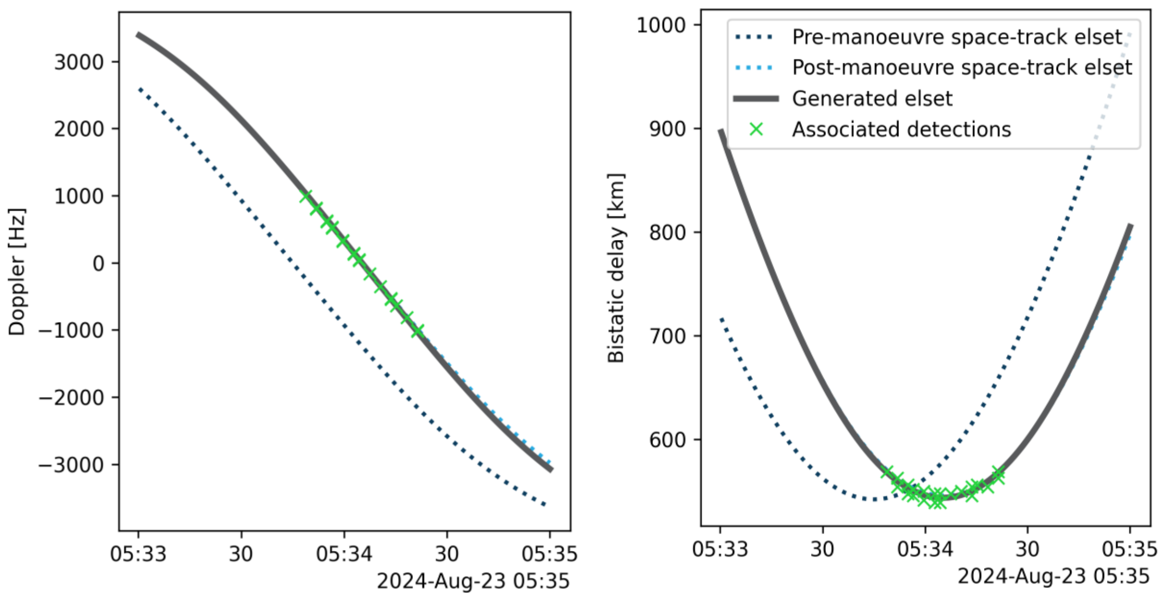

Fig. 5. Generated elsets of a manoeuvre RSO from the un-cued detections versus space-track elsets published pre and post-manoeuvre. Post-manoeuvre space-track elsets lie under the generated elset.

5. CONCLUSION

To address the limitations of a cued system, Silentium Defence has recently developed a fully un-cued processing capability for SSA. Further, the implemented processing approach has significantly reduced the latency of the radar, increased the track capacity, and allowed the MAVERICK OmniGuard to provide situational awareness in both air and space modes simultaneously. Since this processing operates completely independent of the cued information, it unlocks the potential of passive radar for applications in launch and re-entry support.

In this paper, Silentium Defence has shown examples of the ability to apply the un-cued processing techniques for the detection and tracking of RSOs in LEO. An example has been presented showing the detection of 17 RSOs across a 10-minute interval -one of which was yet to be associated with a catalogued object - representing roughly a

[1] Due to the relatively short observation interval, it is difficult to accurately estimate the eccentricity for an IOD. The alignment between the IOD and post-manoeuvre elset is typically greater half an orbit later.

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6-fold increase in the capacity of Silentium's extant cued processing mode. Furthermore, this processing mode has been shown to produce tracks with a significant latency reduction compared to the extant processing technique. Silentium Defence is looking to provide such data to end users within 5-minutes of a RSO pass.

To further demonstrate the utility of this un-cued capability a pass of the ISS immediately after a manoeuvre, and before publicly updated elsets were published, has been presented. Using this pass as a surrogate for a new launch, Silentium Defence has shown the ability to produce a functional IOD from the un-cued detections.

Silentium Defence will soon be offering un-cued space surveillance capabilities as part of its SpaceWatch SSA data-as-a-service products. It is anticipated this service will be of particular interest to a range of SSA data consumers including launch providers, satellite operators, and national space agencies that are seeking to monitor by re-entry events.

6. REFERENCES

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