Australian Space Situational Awareness Capability Demonstrations

Brittany Morreale
United States Air Force

Travis Bessell, Mark Rutten and Brian Cheung
National Security and Intelligence, Surveillance and Reconnaissance Division
Defence Science and Technology Group, Australia

ABSTRACT

Australia is increasing its contribution to the global space situational awareness (SSA) problem by committing to acquire and operate SSA sensors. Over the last year, a series of collaborative SSA experiments have been undertaken to demonstrate the capabilities of Australian sensors. These experiments aimed to demonstrate how existing Australian sensors could perform in a surveillance of space role, prove passive radar's capability to observe low earth orbit (LEO) satellites and perform SSA handoffs to optical sensors. The trials established a data sharing and communications protocol that bridged defence, academia, and industry partners.

Geographically dispersed optical assets, including the Falcon telescope in Canberra, Raven telescopes in Exmouth (Western Australia) and Defence Science and Technology (DST) Telescopes in Adelaide (South Australia) collected on LEO satellites and established cueing protocols. The Murchison Widefield Array (MWA) located in Western Australia, demonstrated the capability of passive radar as an SSA asset after successfully observing LEO satellites based on reflected terrestrial radio signals. The combination of radar and optical SSA assets allows for the exploitation of each sensors unique advantages and locations across the Australian continent.

This paper outlines the capabilities and diversity of Australian optical and radar sensors as demonstrated by field trials in 2016 and 2017. It suggests future potential for harnessing novel radar and optical integration techniques to supplement high-value assets such as the Space Surveillance Telescope as part of the Space Surveillance Network.

1. INTRODUCTION

With the surge of small satellite programs, space is becoming ever more congested, contested and competitive. CubeSats have disrupted the traditional satellite control paradigm and pose both a threat and opportunity to Australia and its partners [1]. The application of non-traditional sensors to the problem of space command and control has led to a fruitful partnership between Defence Science and Technology (DST) Group, international partners, academia, and industry. In a series of trials leveraging sensors across the Australian continent, a more flexible and responsive solution to SSA is explored. Furthermore, trials established a data sharing and communications protocol that bridged defence, academia, and industry partners. Geographically dispersed optical assets, including the Falcon telescope (Canberra), Raven telescopes (Exmouth, Western Australia), and DST Telescopes (Adelaide, South Australia), collected on LEO satellites and established cueing protocols. DST and Western Sydney University continue to test the capability of neuromorphic sensors for faint object detection and characterisation. DST is engaged with The Technical Cooperation Program (TTCP) and Combined Space Operations (CSpO) partners to contemplate the future of space command and control. The combination of radar and optical, traditional and non-traditional SSA assets allows for the exploitation of each sensor's unique advantages in diverse locations.

Australia is increasing its contribution to the global space situational awareness (SSA) problem by committing to acquire and operate SSA sensors. Over the last year, a series of collaborative SSA experiments have been executed to demonstrate the capabilities of existing Australian sensors in the optical and radar regimes. The experiments have shown passive radar's capability to observe LEO satellites and the ability to perform cueing to optical sensors. Furthermore, non-traditional sensing and data processing techniques were explored.

Experiments undertaken over 2016 and 2017 have proven the capability to track space objects of varying sizes and orbital regimes. This paper details these experiments and the unique sensors that were used. Section 2 describes the configuration of the radar and optical sensors, section 3 and 4 detail the planning and execution of the experiments respectively while section 5 concludes with some outcomes and future capabilities as a result of the successful campaigns.

2. EXPERIMENTAL SENSORS

The capability demonstrations and co-collects were specifically tailored to incorporate the maximum number of government, research and development as well as university participants. Based on this desire, the following sensors were selected for inclusion in the 2016 and 2017 capability demonstrations:

- Murchison Widefield Array (MWA)
- DST Group Telescopes
- University of New South Wales Falcon Telescope
- Raven Telescopes
- Event Based Sensors (EBS)

System descriptions of the DST Group Telescopes, Raven Telescopes, and the Falcon Telescopes have been detailed previously [2-4]. These optical Commercial off the Shelf (COTS) systems are closely related in terms of mount specifications, camera types, and aperture sizes (0.3 - 0.5 m). The USAFA-UNSW Falcon telescope has a narrow field-of-view with f/8.1 while the DST Telescopes and US-owned Raven telescopes and have wider field-of-views at f/3-f/5. Figure 1 shows the geographic distribution of these sensor systems across the Australian continent. Below is further description of Australian based MWA and EBS experimental sensors.

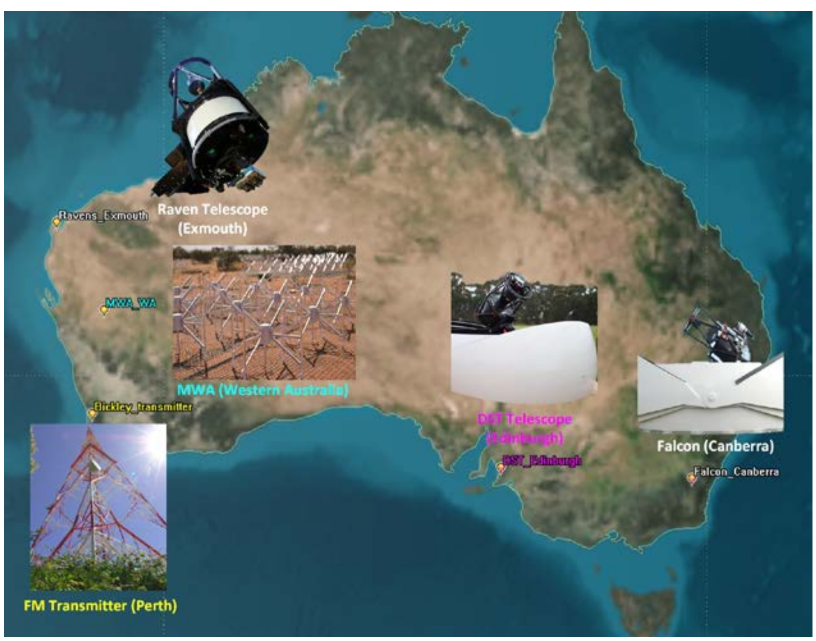

Fig. 1. Geographic distribution of optical and radar sensors across the Australian continent

2.1. Murchison Widefield Array (MWA)

The MWA is a radio astronomy instrument located in Western Australia at the future site of the Australian Square Kilometre Array (SKA) [5]. The site is managed by Curtin University's International Centre for Radio Astronomy Research. The array consists of 2048 dipole antennas dispersed over a region of more than a 1.5km in diameter and operates at a low frequency (80-300MHz). Its primary research has focused on astrophysics and space weather. In 2015, the Passive Radar team at DST Group identified the MWA as a potential passive receiver of terrestrial RF signals of opportunity [6] with the detection of the International Space Station as shown in Figure 2. Since then, the exploration of the MWA's capability as a passive wide area SSA sensor became a part of the DST Group's passive radar research program in partnership with Curtin University.

Correlating the transmitted signal from an FM radio source in Perth (labelled as Bickley in Figure 1 approximately 600km from the MWA) with the signals received by the MWA produced bistatic range and Doppler measurements of the satellites. These are measured along with the observed angles that are part of the standard radio astronomy processing chain. The MWA is designed to observe large parts of the sky, so in a passive radar configuration the sensor can perform a true surveillance role, detecting new objects uncued. The huge data volumes produced by the MWA currently prohibit any real-time processing of the data, but it was shown that the measurements collected on a satellite from a single pass would be adequate to cue a higher precision down-range sensor [6].

Objectives of the MWA capability demonstration included:

- Passive radar characterisation
- Uncued detection of large LEO satellites
- Comparison of daytime and night-time LEO observations

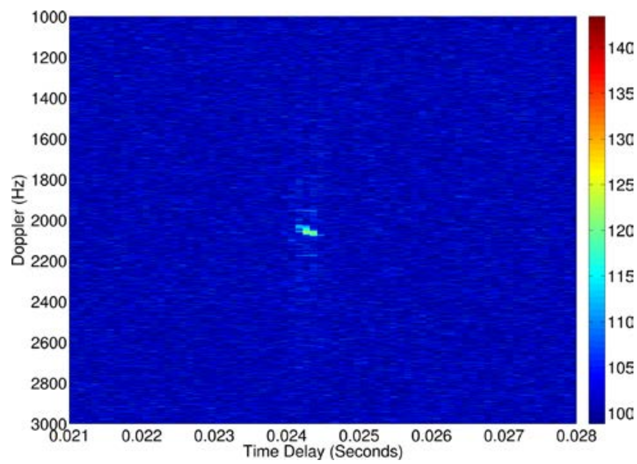

Fig. 2. Passive detection of the International Space Station by the Murchison Widefield Array from reflected FM terrestrial transmissions

2.2. Event Based Sensors (EBS)

The DST Group was introduced to EBS technology by Western Sydney University's (WSU) MARCS institute Biomedical Engineering and Neuroscience Program. EBSs are a neuromorphic imaging technology that apply biologically inspired retinal functions to combine low power consumption and low data rate with high sensitivity. In contrast to a traditional CCD, which produces frames of pixel intensities, an EBS generates asynchronous events for each pixel. Each time a pixel changes in intensity an asynchronous event is generated, which form a continuous stream of events. A prototype IniLabs DAVIS sensor was integrated with a DST 8 inch telescope to demonstrate potential SSA applications. Using this combination, daytime observations of the LEO objects were performed as shown in Figure 3. Information about the technology and its potential applications has been elaborated by Western Sydney University [7, 8]. Through the experiments described below and future planned trials, DST Group in partnership with WSU is exploring the sensors capabilities for terrestrial and space-based SSA missions.

Objectives of the EBS capability demonstration included:

- Sensor characterisation
- Night-time observations of LEO and GEO satellites
- Day-time observation of LEO satellites
- Comparison of sidereal and rate-tracking collections

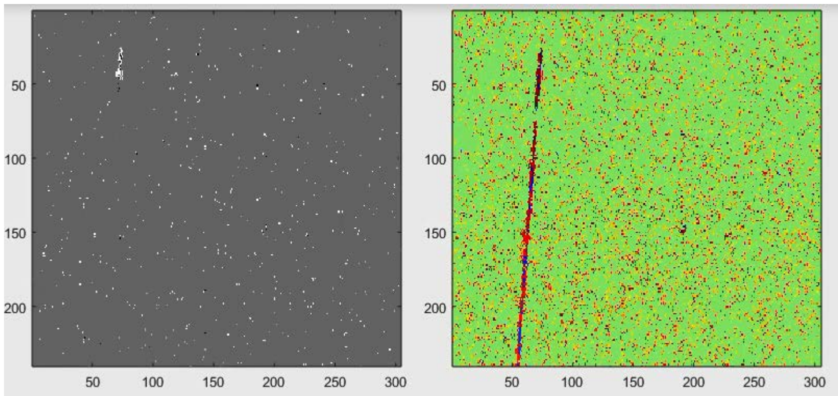

Fig. 3. Daytime observation of LEO satellite using event based sensor.
Left-hand greyscale image shows change detection sensor.
Right hand image shows integrated magnitude of change detections.

3. PLANNING PHASE

To evaluate the capabilities of Australian based SSA assets, a range of experiments were conducted over 2016 and 2017. These experiments leveraged both the geographic diversity and the modes (optical/radar) of the sensors. Experimental sensors were brought together in collaborative testbeds to advance R&D development in conjunction with the necessary cooperative framework for networked operations. The experiments conducted included:

- Nov 2016 – MWA and Optical Co-collect 1
- Dec 2016 – MWA and Optical Co-collect 2
- Feb 2017 – Optical and Event Based Sensing Co-collect
- March & April 2017 –Event Based Sensing Capability Exploration

A number of overarching objectives were identified during the planning for the capability demonstration. These included:

- Exploring the utility of operational and experimental optical and passive radar sensors to support SSA missions
- Understanding the capabilities and limitations of passive radar as an SSA asset
- Identifying and trialing data sharing and coordination mechanisms to utilise various SSA sensors within the research community
- Promoting enhanced cooperation between governments (US and AUS), the R&D community and academic institutions in managing Australian-based SSA assets

4. EXPERIMENT EXECUTION

The framework for data sharing, communication, and cooperation became an integral part of the planning and execution. This section provides more detail on the four co-collect experiments that occurred from November 2016 through to April 2017.

4.1. November 2016

The first multi-sensor experiment included participation from the DST telescope and passive radar team, Murchison Widefield Array (MWA), Raven telescopes and other Australian assets. The goal of this experiment was to prove passive radar's capability to observe LEO satellites with optical observations to validate the observations. The co-collect aimed to ascertain future potential to perform real-time handoffs from passive radar to optical sensors. To achieve this objective three key targets were chosen based on their size, orbital altitude, and availability of reliable TLEs as shown in Figure 4. These initial targets also allowed geographically distributed sites to exercise communication channels during the exercise. In this first phase of the campaign, the sensor sites successfully achieved passive and optical co-collects on five LEO satellites, as well as optical observations of twenty LEO satellites. This experiment showed the viability of optical and passive radar as SSA tools and the potential for sensor cueing.

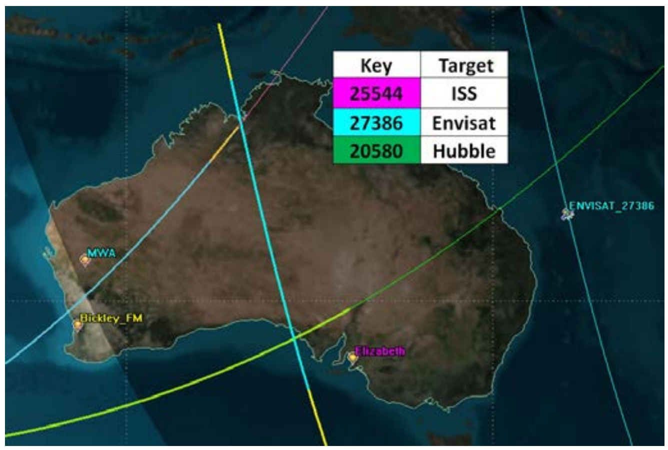

Fig. 4. Ground traces of three large objects relative to sensor locations used in co-collect campaign during November 2016

4.2. December 2016

The second phase of multi-asset experiments included the DST telescope and passive radar team, MWA, the Raven telescopes and other Australian sensors. The goal of this experiment was to test passive radar's capability to observe various classes of LEO satellites and perform orbit determination for SSA handoffs to optical sensors. Three target satellites were chosen as control targets as shown in Figure 5. In addition, a set of five additional LEO targets were chosen based on varying sizes, orbital parameters, and visibility.

4.3. February 2017

In early 2017, DST Group led an Australia-wide co-collect campaign utilising the DST telescope, the Raven telescopes, Falcon telescope (Canberra), Event Based Sensor, and other Australian sensors. The experiment involved sensor cueing based on optical observations taken by the Falcon telescopes. The experiment coincided with the launch of 104 satellites from the Indian Space Research Organisation's (ISRO) Polar Satellite Launch Vehicle [9], enabling DST Group and UNSW to trial a communication and cuing protocol. UNSW successfully acquired the CubeSats from this launch and performed orbital estimates. Unfortunately, adverse weather conditions in Adelaide prevented the DST optical assets from reacquiring the targets. However, this effort formed the foundation for a cueing handover process to maintain custody of satellites shortly after launch and refine orbital parameters. Multiple sites achieved successful co-collects and communicated the data to DST Group for post-processing.

Fig. 5. Ground traces of three large objects relative to sensor locations used in co-collect campaign during December 2016

4.4. March and April 2017

From March to April 2017, DST and Western Sydney University conducted a dedicated EBS experimental campaign over several weeks with two EBS models (ATIS and DAVIS sensors). This multi-week experiment included objectives to demonstrate the EBS sensor's capability to perform both night-time and day-time observation of LEO and GEO satellites. The experimental campaign aimed to capture a variety of classes of observations, varying targets by orbital regimes from LEO to GEO and visual magnitude, and exercising alternative acquisitions methods such as rate-tracking, scanning, and leapfrogging. The DST and WSU team completed each of the experimental objectives proving EBS sensor's potential to perform SSA from LEO to GEO on targets down to magnitude 11.

5. CONCLUSION

The multi-sensor co-collects and capability demonstrations achieved each of the overarching objectives. The exercises effectively demonstrated the utility of Australian based operational and experimental optical and passive radar sensor's capabilities to support SSA missions. Additionally, the co-collect experiments provided an initial understanding of the capabilities and limitations of passive radar as an SSA asset. Further exploration of this capability is ongoing. Each of the experiments have worked toward coordinating a geographically diverse set of networked sensors, identifying and trialing data sharing and coordination mechanisms within the research community. Furthermore, the groundwork was laid for enhanced cooperation between governments, the R&D community and academic institutions in managing Australian-based SSA assets.

Future SSA research within DST will be focused around further refining the understanding of niche sensing technologies and how to best exploit that information as a network of cooperative sensors. These requirements are aligned with Australian defence needs and international partners. Experimentation and analysis of experimental outcomes is a key component of DST's SSA research. Passive radar and event-based sensors are two new technologies that will be a significant part of ongoing sensor research in Australia. Additional Australian niche sensing technologies which could contribute to SSA include Curtin University's Desert Fireball Network [10] and High Frequency Line-of-Sight radar [11]. Integration of the sensor information into a catalogue of objects, either to augment an existing catalogue, or to provide initial orbit determination, will be investigated by extending novel state estimation techniques [12].

Australia has defined itself as a testbed for sensing technologies that will shape the future of space command and control. As Australia's R&D and academic communities develop new avenues for space management and exploitation, the ability to effectively utilise diverse sites and fuse data will define future success.

REFERENCES

[1] National Academies of Sciences, Engineering, and Medicine. 2016. *Achieving Science with CubeSats: Thinking Inside the Box*. Washington, DC: The National Academies Press.
[2] F. Chun, R. Tippets, M. Dearborn, K. Gresham, R. Freckleton and M. Douglas, "The U.S. Air Force Academy Falcon Telescope Network," in Proc. the Advanced Maui Optical and Space Surveillance Technologies Conf., (AMOS), 2014.
[3] P. Sydney, J. Africano, A. Fredericks, K. Hamada, V. SooHoo, D. Nishimoto, P. Kervin, S. Bisque and M. Bisque, "Raven Automated Small Telescope Systems," in Proc. SPIE 4091, Imaging Technology and Telescopes, 2000.
[4] T. Hobson, V. Clarkson, T. Bessell, M. Rutten, N. Gordon, N. Moretti and B. Morreale, "Catalogue Creation for Space Situational Awareness with Optical Sensors," in Proc. the Advanced Maui Optical and Space Surveillance Technologies Conf., (AMOS), 2016.
[5] S. J. Tingay, R. Goeke, J. D. Bowman, D. Emrich, S. M. Ord, D. A. Mitchell, M. F. Morales, T. Booler, B. Crosse, R. B. Wayth, C. J. Lonsdale, S. Tremblay, D. Pallot, T. Colegate, A. Wicenec, N. Kudryavtseva, W. Arcus, D. Barnes, G. Bernardi, F. Briggs, S. Burns, J. D. Bunton, R. J. Cappallo, B. E. Corey, A. Deshpande, L. Desouza, B. M. Gaensler, L. J. Greenhill, P. J. Hall, B. J. Hazelton, D. Herne, J. N. Hewitt, M. Johnston-Hollitt, D. L. Kaplan, J. C. Kasper, B. B. Kincaid, R. Koenig, E. Kratzenberg, M. J. Lynch, B. Mckinley, S. R. Mcwhirter, E. Morgan, D. Oberoi, J. Pathikulangara, T. Prabu, R. A. Remillard, A. E. E. Rogers, A. Roshi, J. E. Salah, R. J. Sault, N. Udaya- Shankar, F. Schlagenhaufer, K. S. Srivani, J. Stevens, R. Subrahmanyan, M.Waterson, R. L.Webster, A. R. Whitney, A.Williams, C. L.Williams, and J. S. B. Wyithe, "The Murchison Widefield Array: The Square Kilometre Array Precursor at Low Radio Frequencies," Publications of the Astronomical Society of Australia, vol. 30, p. e007, Jan. 2013.
[6] J. Palmer, B. Hennessy, M. Rutten, D. Merrett, S. Tingay, D. Kaplan, S. Tremblay, S. Ord, J. Morgan and R. Wayth, "Surveillance of Space using Passive Radar and the Murchison Widefield Array," in Proc. IEEE Radar Conference, (RadarConf), 2017.
[7] G. Cohen, "Event-based feature detection, recognition and classification," Ph.D. thesis, Western Sydney University, 2015.
[8] G. Cohen, S. Afshar, A. van Schaik, A. Wabnitz, T. Bessell, M. Rutten and B. Morreale, "Event-based Sensing for Space Situational Awareness," in Proc. the Advanced Maui Optical and Space Surveillance Technologies Conf., (AMOS), 2017.
[9] Indian Space Research Organisation (ISRO). PSLV-C37 Launch, http://www.isro.gov.in/, 2017.
[10] P. Bland, "Adapting a Planetary Science Observational Facility for Space Situational Awareness," in Proc. the Advanced Maui Optical and Space Surveillance Technologies Conf., (AMOS), 2016.
[11] G. Frazer, M. Rutten, B. Cheung, and M. Cervera. "Orbit determination using a decametric line-of-sight radar." In Proc. the Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), 2013.
[12] N. Moretti, M. Rutten, T. Bessell and B. Morreale. "Autonomous space object catalogue construction and upkeep using sensor control theory." in Proc. the Advanced Maui Optical and Space Surveillance Technologies Conf. (AMOS), 2017.