The EOS Space Debris Tracking System

Craig H. Smith
EOS Space Systems Pty Ltd

Abstract

EOS Space Systems (EOS) has designed, built and demonstrated a capability to track tiny pieces of space debris, using laser tracking system.

EOS uses a visible light acquisition/targeting system and an infrared laser tracking system to track objects smaller than 10 cm in diameter, with unprecedented accuracy (<1m ranging).

The EOS Space Debris tracking system has been successfully proven in formal demonstrations of capability (code named RazorView) to the US Air Force in June-August 2004.

The capability to track and catalogue large numbers of debris objects, makes it possible to navigate safely through the space debris fields. This capability protects satellites (civilian and military) and is now being planned for an expansion into a world wide network of space debris tracking stations.

1 The EOS Space Debris Tacking System and RazorView Demonstration

In 2002, EOS contracted with the US Air Force to provide an active demonstration of its capability to track small space debris objects using lasers. The demonstration code name was RazorView.

The Razor View (RV) project was a program to demonstrate an **operational** capability for tracking small space debris objects using laser ranging techniques.

1.1 Original (2002) Ranging Station

The RazorView demonstration was originally slated to be undertaken at the original Mt Stromlo ranging station (pictured below). This system performed well (see track data below) but needed some system upgrades in order to meet the full RV system demonstration requirements.

The ranging station went into stand-down in December 2002 to perform system upgrades.

Fig 1. EOS Mt Stromlo ranging station with 75cm telescope in 2002.

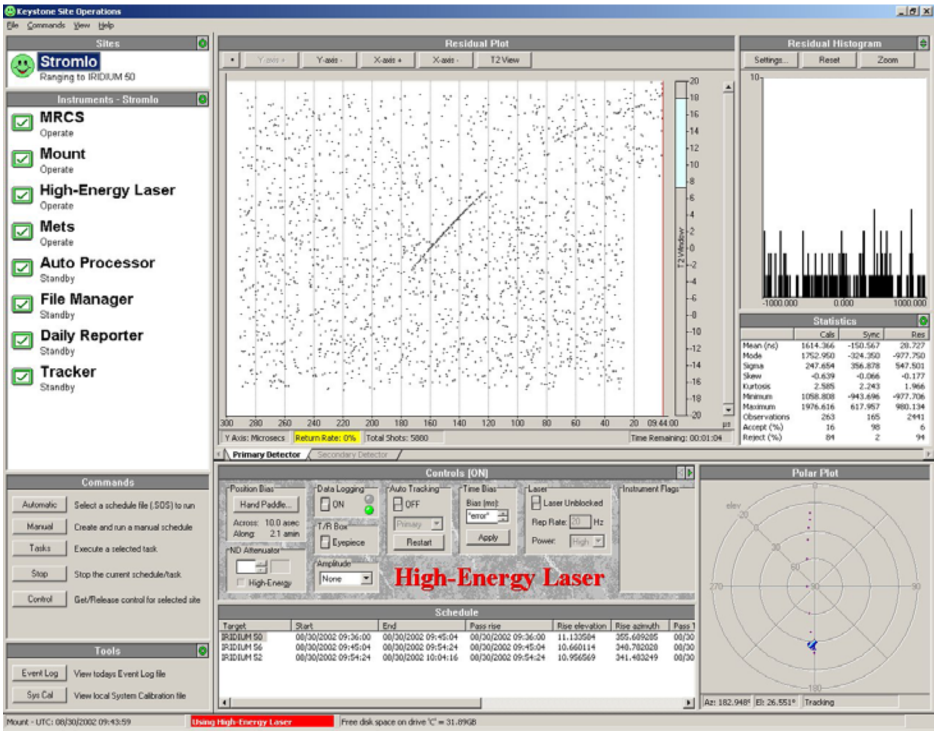

Fig 2. Typical track data from RV target acquired during tracking session in August 2002.

1.2 Destruction of Ranging Station

Before the ranging station upgrades could be completed wildfires swept through Canberra (Jan 18, 2003) completely destroying the ranging station and all of its contents.

Fig 3. Mt Stromlo Observatory Ablaze (Jan 18, 2003)

Fig 4. EOS Ranging Station after Fire

Fig 5. 75cm telescope after fire

1.3 Reconstruction of the Space Research Center

After the fires the RV contract was suspended for a period of 12 months to enable EOS to rebuild the facility and resume operations. While a serious delay to the RV demonstration, the reconstruction also allowed EOS to demonstrate its claimed capability to manufacture and install a Debris Tracking station in 12 months or less.

Unfortunately building permits and insurance payments for the reconstruction were not forthcoming until after June 2003. However, once funds and permits were received reconstruction moved apace. Below are a series of images showing various stages of the re-construction.

.

.

Fig 6. Laser and Control Room Construction

Fig 7. Laser and Control Room Construction

Fig 8. Installation of the 1.8m telescope

Fig 9. Installation of Laser Tables

Fig 10. EOS Space Research Centre in Oct 2003

Clearly EOS was successful in demonstrating the construction of a complete Space Debris and Satellite Ranging Station in less than 12 months. The System architecture and performance are discussed below.

2 System Description

The ranging activities were performed at the EOS Space Research Centre located at Mt Stromlo (pictured below).

Fig 11. EOS Space Research Centre, as configured for the RazorView demonstration.

2.1 System Architecture

The Space Debris tracking station is currently configured with 1.8m, 1.0m and 0.35m telescopes. All of the RV demonstration activities were completed using the 1.8m telescope.

The debris tracking system is constructed from five basic sub-systems:

1. Target Acquisition System (TAS)
2. Beam Locking System (BLS)
3. High Energy Laser (HEL)
4. Beam Delivery System (BDS)
5. Ranging Transceiver System (RTS)

2.2 Target Acquisition System (TAS)

The TAS is used to detect a target and center the target in the Beam Locking System field of view (FOV). The TAS uses an f/0.75, wide field telescope and CCD capable of detecting moving debris objects even against the strong Canberra sky background. A camera layout is shown in Fig 12. The optical design is proprietary to EOS and provides excellent mage quality over a wide field for this extraordinarily fast optical beam.

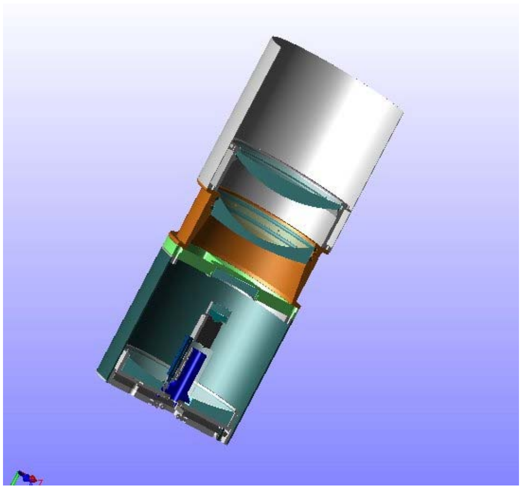

Fig 12. TAS Camera Section View

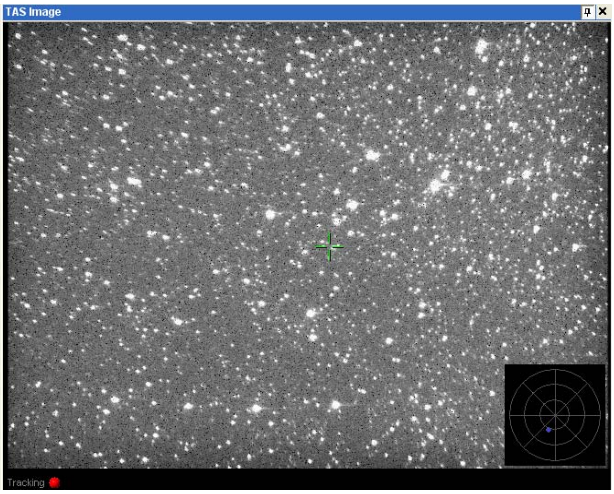

Fig 13. Typical TAS view. Note satellite track crossing lower left to upper right.

2.3 Beam Locking System (BLS)

The BLS is a high sensitivity CCD at the end of the 1.8m telescope coude path. This camera locks the visible target to the laser bore sight to sub-arcsecond accuracy. This camera is able to easily detect all targets seen in the TAS, having the advantage of a 1.8m diameter collecting area. This camera drives the telescope and fast steering mirror servo loops.

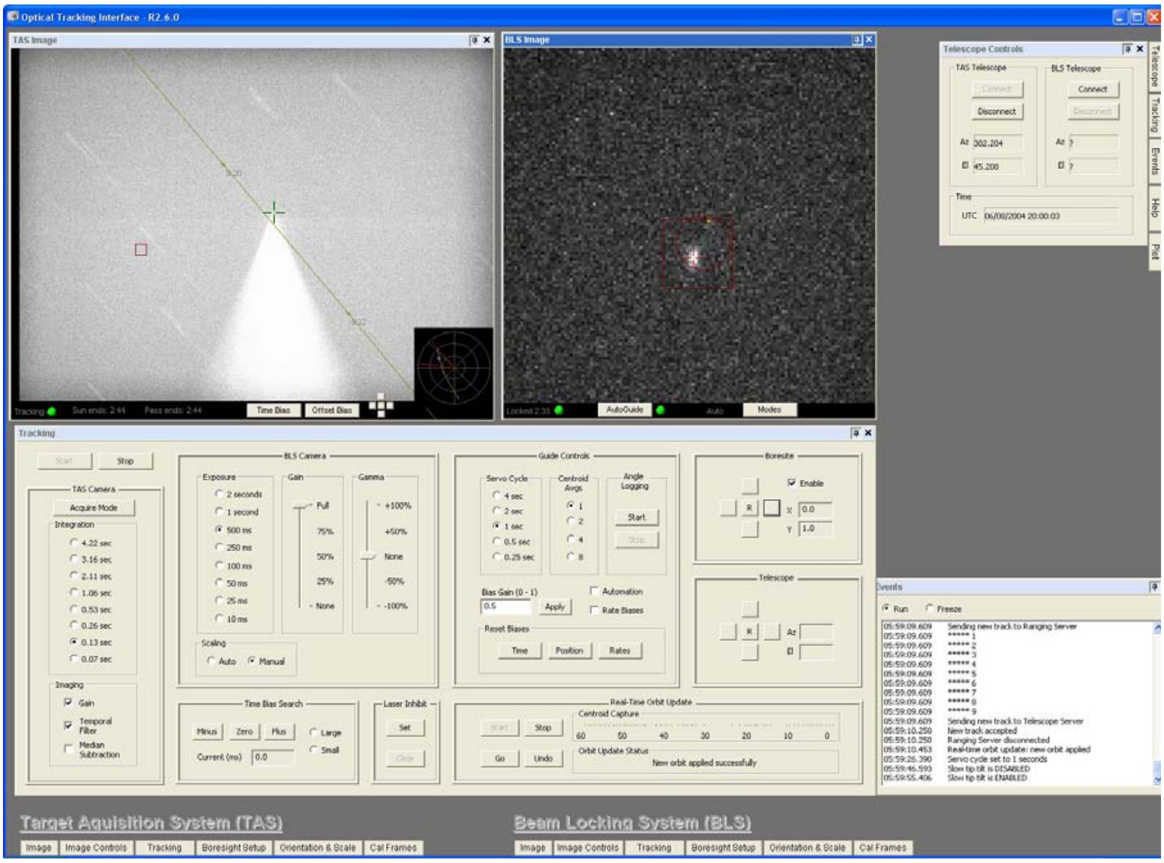

Fig 14. Typical screen showing TAS and BLS working in co-operation.

Upon initial acquisition the TAS has control of the telescope tracking servo system, until the target appear in the BLS FOV. At this point the TAS hands-off to the BLS for fine guiding and beam locking.

2.4 High Energy Laser (HEL)

The HEL is the main ladar ranging laser. The HEL is a Nd:YAG laser operating at 1.064um and providing 100W average power at 50 Hz.

Beam quality and stability are critical requirements for the system is to deliver the energy efficiently to the target. This laser provides beam quality of X1.2 Diffraction Limited and a beam pointing stability of less than 1 arc-second at 50 Hz.

The laser operation is fully automated under software control, and needs minimal maintenance. The laser typically used every night for 6 months or more before any maintenance or alignment is required.

2.5 Beam Delivery System (BDS)

From the HEL, the beam is expanded up and then conveyed by the coude optics to the beam delivery telescope. This is a 1.8m high performance telescope in Mersenne (beam expander) configuration, installed in a 9m co-rotating IceStorm enclosure. The BDS system is configured to provide optimum throughput, using proprietary coatings, high laser damage resistance, minimal degradation of beam quality and high performance tracking capability for LEO targets.

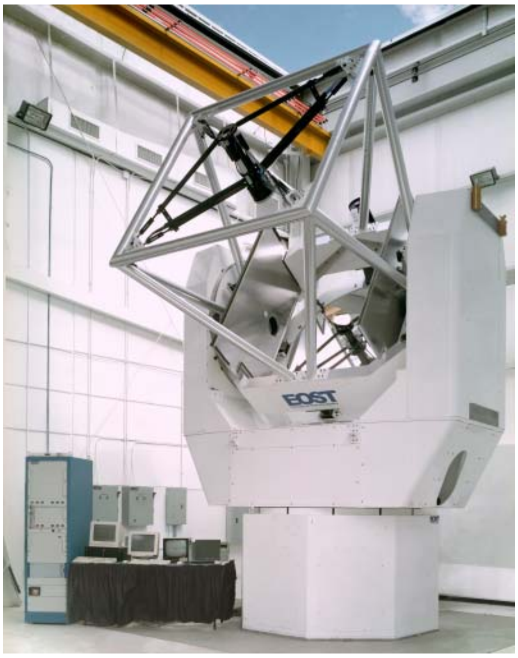

Fig 15. 1.8m beam delivery telescope

Fig 16. BDS in IceStorm enclosure

The beam director telescopes are capable of providing absolute pointing of ~1.5 arcsec rms, anywhere on the sky and provide tracking (beam pointing stability) to better than 50milli-arcseconds rms over any 10 second period. The optical system is capable of providing 85nm rms wavefronts, though beam projection is limited by atmospheric turbulence. The beam quality degradation by the atmosphere is minimized by careful control of the thermal environment, as any differences between the temperature of the telescope optics and the air can lead to thermal plumes causing air turbulence. The telescope and enclosure minimize these effects by ensuring that air is able to flow through the enclosure and across the telescope. The enclosure is insulated to minimize day time heating and all of the telescope optics are light-weighted to ensure they are able to track the ambient temperature.

The telescope and enclosure are both manufactured by EOS.

2.6 Ranging Transceiver System (RTS)

The RTS provides transmit and receive multiplexing, as well as time of flight measurements for the ranging pulses. All of the RTS technology is EOS proprietary. The timing systems provides timing accuracy of ~10 pico seconds rms. The detectors are able to detect a single return photon from each laser pulse.

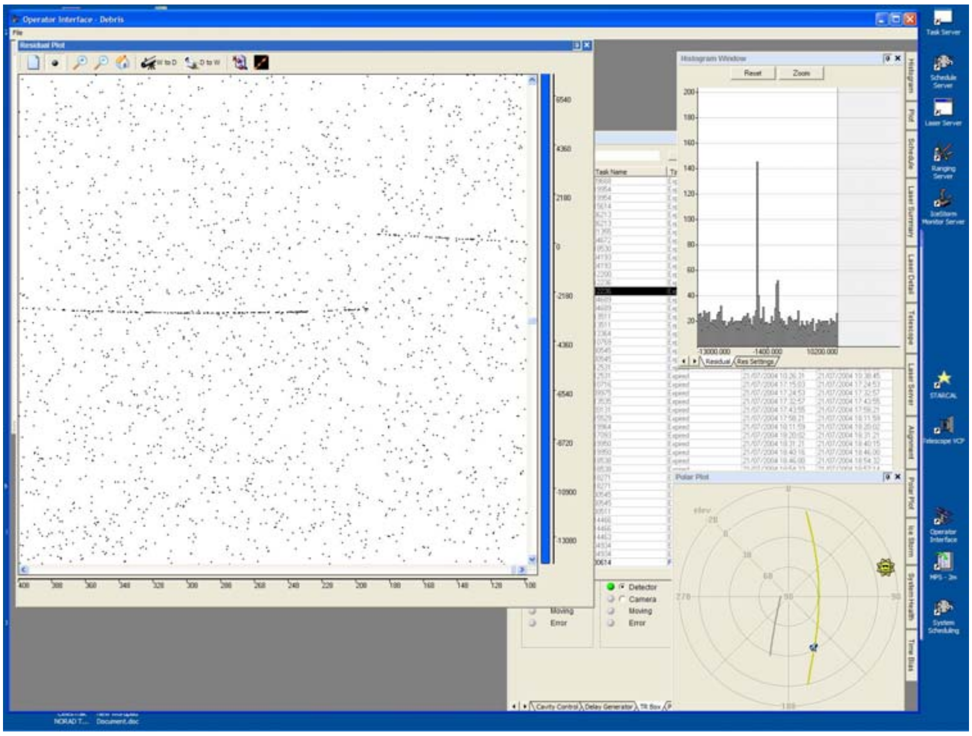

Fig 17. Typical track output from RTS. Other screens in thus view show the target trajectory and telescope position (polar plot) and the range residual histogram.

The ranging screen (upper left in fig 17) shows the detected photon returns. Each dot represents a single photon detection. The random dots are largely thermal noise in the detector, but the target track is a clear trace through the center of the frame. The axis are time on the abscissa (with 0 or current epoch at the lower right corner). The vertical axis shows the range residual, which plots the difference between measured and predicted range to the target measured in pico-seconds. The discontinuity in the trace shows where a real time orbit update has been completed, and it is clear that the range residual is much closer to zero after the update, indicating a significantly improved orbit prediction.

The window behind the ranging screen shows the system autonomous scheduling (behind in upper right). Here a whole night's targets are loaded into a schedule and the system tracks each object autonomously.

3 System Performance

After initial integration issues the system performed much as system link-budget estimates predicted.

The size of the objects tracked and accuracy of the orbits determined are not public information, but customer reports relating to the RazorView demonstration state that ALL demonstration objectives were met, and objects less than 10cm in size were tracked by the system.

Nearly 100 debris objects were tracked by laser during the final demonstration of the system performance and precision orbits for each of there objects were provided to the customer.