By Hubert Foy

Building the World's First Automated Space Debris Tracker

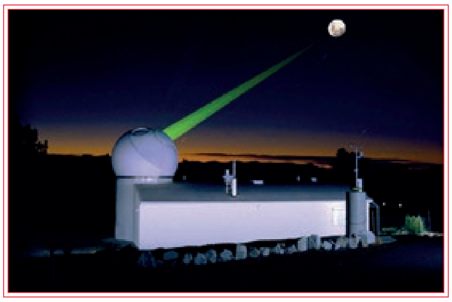
EOS Satellite Laser Ranging and Space Debris Tracking Station at Australia's Mount Stromlo Observatory in Canberra. - Credits: EOS

Since the launch of Sputnik I in 1957, more than 6,000 spacecraft have been successfully sent into Earth orbit. Each launch – whether successful or not – contributes to the release of human-made debris in Earth orbit. This "space junk" consists of expired spacecraft, spent rocket bodies, mission related objects, and fragmentation debris. A majority of debris remains in orbit indefinitely, but their orbits drift due to the effect of Earth's atmospheric drag, a force that extends far into space.

Debris poses a real collision threat to deployed spacecraft. NASA's Debris Office estimates that as many as 300,000 objects larger than 1 centimeter are present in low Earth orbit alone. The U.S. Space Surveillance Network, consisting of 29 optical telescopes and radar sensor sites worldwide, currently tracks about 20,000 human-made space objects as big as a baseball (10 centimeters in diameter) or larger, each capable of destroying a satellite. The only protection against this larger debris is to alter the trajectory of a spacecraft to avoid a collision, a maneuver that can be expensive in terms of fuel and mission downtime.

The Cosmos-Iridium accident showed that satellite collision is a reality

In 2009, five different NASA robotic spacecraft, as well as the Space Shuttle and the ISS, conducted collision avoidance maneuvers. The destruction of the operational U.S. Iridium 33 communication satellite after a collision with the decommissioned Russian Cosmos 2251 spacecraft in 2009 showed that collision is not just a statistical probability: it is a reality. The incident underscores the inadequacy of current measures and capabilities to detect and predict



Artist's impression of the tracking station during operations. - Credits: EOS collisions, and the importance of improving precision orbit determination and prediction.

Using the reflection of laser light to measure the distance of space debris from a ground-based station is one possible way to improve debris tracking accuracy. The Australian company Electro Optic Systems (EOS) is developing the world's first automated laser tracking technology that would track potentially damaging debris as small as a few centimeters. Once a debris object is tracked, satellite operators would be able to enact a collision avoidance maneuver.

Automated Laser Tracking System

A consortium of scientists and design engineers at EOS developed the automated laser tracker project in 2010 with an AUD 4.04 million (USD 3.6 million – 2010 exchange rate) grant from the Australian Space Research Program. The project is aimed at upgrading EOS' current manned tracking capability at Australia's Mount Stromlo Observatory in Canberra to reduce operation cost. Professor Yue Gao, Head of Laser Research and Development Division at EOS Space Systems Pty Ltd, is one of the chief designers. Space Safety Magazine contacted Prof. Gao to get some insight into the research and development behind the project.

> "A high energy laser system can tell the range, azimuth, and elevation from a single station"

Prof. Gao, who joined EOS in 1994, has worked on projects and systems for space, military, and scientific applications. He was project manager and chief investigator of the laser ablation study for space debris deorbiting. He has led investigations on different studies related to solid state laser systems, laser guide star for adaptive optics, and space debris tracking systems. "On EOS laser projects I have worked as a project manager and chief designer of the laser systems, and one of the system designers for the whole tracking system," he adds.

"EOS is developing the capability of fully remote and automated operation of a high performance tracking station, responsive space debris orbit determination, and space debris crash de-confliction," explains Prof. Gao.

The automated tracking system offers prospects of a technology breakthrough that could determine debris orbits in space with sufficient accuracy to improve situational awareness of space assets and allow cost-effective mitigation of debris risk.

"EOS currently has two laser systems located in Australia, one Satellite Laser Ranging (SLR) and one laser system for monitoring space debris," says Prof. Gao, adding that the team at EOS is not aware of any competitors to the project at the moment, although other countries such as China and Germany have been pursuing this technology in the last few years.

EOS has a long standing reputation in space surveillance and monitoring services. Almost all of the critical components for the tracking system, including the laser, telescope, timing systems and control systems were developed in-house by EOS. According to Prof. Gao, "these new features are expected to achieve most of the performance milestones in late 2013." He then adds that "they can significantly reduce the cost of providing debris protection to satellites and would ease the integration of the capability into the operational processes of key users."

"The tracking technology is a combination of high pulse energy and high repetition rate laser system with Electro-Optic technology that can determine space debris orbit with a range accuracy of 1.5 meters in a second or so," Prof. Gao explains. "It can provide three dimensional data, azimuth, elevation, and range from a single tracking station, and can provide high orbit determination and prediction accuracies."

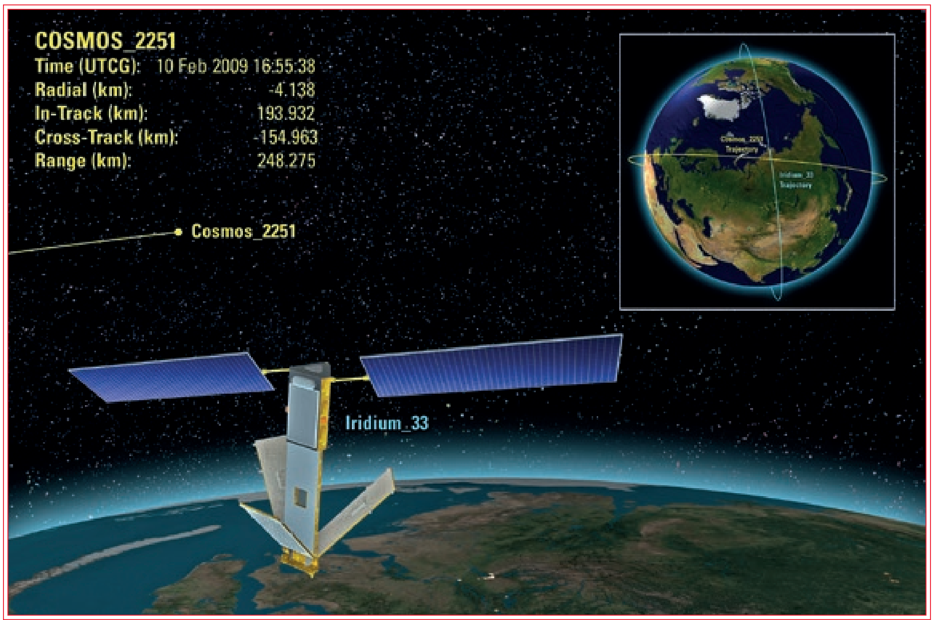


Illustration of the Cosmos-Iridium collision of 2009. The upper right plot shows trajectories of Iridium 33 (blue) and Cosmos 2251 (yellow) at time of collision. - Credits: Analytical Graphics, Inc. (www.agi.com)

Tracking and Monitoring Debris

Current ground-based debris surveillance and monitoring systems, including the automated laser tracking system, have their advantages and disadvantages. A ground-based sensor tracking a space object and determining its position at a given time is referred to as observation. For a single pass of the object in space as it flies in its trajectory, a collection of observations from different sensors constitute a track.

The U.S. Joint Space Operations Center (JSpOC), which gathers ground-based observations of space debris from the Space Surveillance Network, determines how many tracks of

NASA's Satellite Laser Ranging Network uses lasers to measure distances from ground stations to satellite borne retro-reflectors to the millimeter level. – Credits: NASA

data are nominally required to determine each object's orbit primarily based on the object's type, size, and rate of change of its orbit. Because the orbits of debris objects are not stable, the level of positional accuracy obtained with current ground-based tracking systems are inadequate to sufficiently predict in-orbit collision with a degree of certainty.

Ground-based systems are capable of tracking space objects only when the ground area is dark while the object must be illuminated by the sun. This requirement limits the debris-observation window to less than 4 hours for every 24-hour period: usually after sunset and before sunrise. Debris observation is further limited by inclement weather. In order to observe a large debris population in a short period of time, multiple ground stations located around the world are required, a costly proposition. Prof. Gao acknowledges those limitations and explains how they can be mitigated in a laser system.

"Although ground-based laser tracking is negatively affected by the atmosphere, it is mitigated in the technology. The ultimate performance of this technology relies on the ability to focus a laser beam accurately on the space debris," Prof Gao says. "The current laser system is ground based. But atmospheric turbulence does deteriorate the laser beam quality and reduce the system link budget. An adaptive optics system helps to overcome this."

Debris that presents a small profile, either due to actual size or distance from Earth, poses bigger technical challenges. According to Prof. Gao, "there have been difficulties for the current VHF-band radar-based space surveillance system to track objects smaller than 10 centimeters and achieve high orbit determination accuracy due to the fundamental limit of the radar wavelength." He adds that "conventional optical tracking through telescopes cannot tell the range from a single station. However, a high energy laser system can tell the range in addition to the azimuth and elevation from the single station."

Unlike ground-based radar tracking that have limited 'mobility,' ground-based laser tracking has good 'mobility', can move quickly and can thus track targets in any direction.

Laser technology is already used to monitor large objects in space. Ground-based Satellite Laser Ranging (SLR) is currently used to track satellites equipped with retro-reflectors.

> "A combination of radar and laser tracking offers a cost effective and full spectrum solution"

That technique involves the firing of laser pulses through a telescope at passing satellites and measuring the time taken for the pulses to return to Earth. The Australian EOS SLR facilities at Mount Stromlo in Canberra and the Moblas in Western Australia are part of a global network of over 40 observatories using laser light to measure distances to orbiting satellites.

According to Prof. Gao, SLR is, however, not suitable for tracking space debris because its energy level is too low and the retro-reflectors essential for the method to work are completely lacking on debris objects. "Generally speaking, the lasers used for SLR have pico-second pulse width and generate relatively low pulse energy. The laser systems used for SLR are not suitable for tracking space debris," he clarifies.

Looking Forward

Radar tracking has its own advantages, such as the capability of tracking a large number of targets, large data volume, and operating day and night in all weather, Prof. Gao says. "Honestly, laser tracking is never going to take over or supersede radar based systems."

According to Prof. Gao, "active laser tracking is complementary to optical and radar based systems." He adds that "an optimum combination of radar and laser tracking capabilities offers a cost effective and full spectrum solution because each does what they are good at." For example, "radar based monitoring system is good for 24/7 surveillance and maintaining a large volume of objects and orbits." For high interest and potential conjunction objects, "radar can hand over to the laser tracking system for a high precision tracking and orbit update."

Looking forward, Prof. Gao explains how the international aerospace community may benefit from the technology. "Now our laser based tracking system can provide 1.5 arcsecond angular accuracy, better than 5 meter orbital determination accuracy and better than 200 meter predicted orbital accuracy (after 24 hours)," he says. "With the improved orbit predictions, the close approach can be identified, avoidance maneuvers can be conducted, and collision avoided altogether. So space assets can be well protected."