Remote Manoeuvre of Space Debris Using Photon Pressure for Active Collision Avoidance

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International Workshop of Space Debris Management
9 Nov 2018
SERC

- CRC for Space Environment Management operated by the Space Environment Research Centre (SERC)
- Five year program 2014 - 2019
- SERC Partners
  - EOS Space Systems
  - Lockheed Martin Australia
  - Optus Satellite Systems
  - The Australian National University
  - RMIT University
  - National Institute of Information and Telecommunications Technology (NICT) Japan
  - Commonwealth of Australia
SERC Objectives

- Collision avoidance and mitigate Kessler Syndrome

Evolution of the number of objects in orbit [NASA^4]
Collision Avoidance: Active Satellites

• When a conjunction (potential collision) is predicted most active satellites can manoeuvre to avoid the collision.
  – Micro sats and mega constellations challenge that assumption

• But:
  – Manoeuvres use fuel and shorten satellite lifetime
  – Not on station while manoeuvring
  – Many satellite operators choose to ignore collision warnings

• Satellite operators need/want actionable collision warning information
Collision Avoidance: Passive Satellites and Space Debris

- Passive Satellites and Space Debris have no maneuver capability
- When debris collides with debris everyone loses
- So what can we do about debris collisions and pending Kessler Syndrome cascade?
SERC Activities

• SERC is looking at techniques and technologies that can help avoid all types of collisions and preserve the orbital environment for future use.
  – From LEO to GEO and Deep Space
  – For passive and active satellites and debris

• In Deep Space this means actionable threat warning

• In LEO this is threat warning and physically stopping the collisions by remote manoeuvre.
Four Research Programs

- **RP1**: Remote Manoeuvre of Space Debris Using Photon Pressure with Demonstration on Orbit
- **RP2**: New and Improved Orbit Determination and Propagation Techniques
- **RP3**: Conjunction Assessments and Threat Warning Services
- **RP4**: Satellite Based Test Bed
Research Program 1:

Remote Manoeuvre of Space Debris Using Photon Pressure

Primary Contributors to RP1:
- EOS Space Systems
- ANU RSAA
- Lockheed Martin Australia
- SERC
Collision Avoidance

- Two objects at orbital velocities (7.5 km/s) spend <100 µs in the same 3D space.
- If we can shift the point in time that one object reaches an intersection point by 100 µs (1m in along-track) a collision could be avoided.
- In reality it’s a bit more complex than that because our predictions aren’t as good as 100 µs (1m).
- This is avoidance, not removal.
Radiation Pressure

- Photon Energy
- Photon Momentum

\[ E_{ph} := h \cdot \frac{c}{\lambda} \]
\[ p_{ph} := \frac{h}{\lambda} \]
Solar Sail driven by Radiation Pressure
Photon Pressure for Remote Maneuver
How much is enough?

• We are talking about using light pressure to manoeuvre a space debris object. Photon pressure is weak, so we only want to make the smallest change necessary to have an effect.

• So it comes to a balance between
  – how accurately we can measure the position
  – how accurately we can propagate the orbit
  – how far is it practical to move an object using lasers from the ground
Measurement Accuracy

**Azimuth and Elevation Errors**

LAGEOS 1, 30 July 2004

- RMS Angular Error ~1.5 arcsec
- 7m @ 1000km

**Ranging Errors**

LAGEOS 2, 7 November 2004

- RMS Range Error ~1m

Time since the first Epoch (s)
the first epoch is at 17h 17m 21.19304s

Time since the first Epoch (s)
the first epoch is at 12h 52m 35.22594s
Natural Variability

- Plot of in-track variability after 24 hours
- Red and green curves use different A/M estimators
- The majority of objects have in-track uncertainty <100m after 24 hours.
How much velocity change do we need to get 100m separation?

Orbital Velocity

\[ v := \sqrt{\frac{G \cdot M_E}{R_E + \text{Alt}}} \]

\[ v = 7454 \text{ m/s}^{-1} \]

Allocated time to effect change

\[ \Delta \text{Time} := 24 \cdot 3600 \text{ s} \]

Required Along Track Distance after delta T

\[ \Delta D := 100 \text{ m} \]

Required Velocity Change

\[ \Delta v_{\text{desired}} := \frac{\Delta D}{\Delta \text{Time}} \]

\[ \Delta v_{\text{desired}} = 1.157 \frac{\text{mm}}{\text{s}} \]
# System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Altitude</td>
<td>500 km</td>
</tr>
<tr>
<td>Target Diameter</td>
<td>20 cm</td>
</tr>
<tr>
<td>Target Mass</td>
<td>0.2 kg</td>
</tr>
<tr>
<td>Beam Director Diameter</td>
<td>1.8 m</td>
</tr>
<tr>
<td>Laser Power</td>
<td>18 kW</td>
</tr>
<tr>
<td>Laser Beam Quality (M^2)</td>
<td>1.2</td>
</tr>
<tr>
<td>Delivered Strehl</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Effect depends on range, atmosphere, dwell time, orbit geometry…
Force vs Zenith Distance

Allowing for photon flux, range, along track vector and dwell time vs ZD

Integrate under the curve and divide by mass gives

\[ \Delta v = 0.3 \text{ mm/s} \quad \text{or 3 passes for 1 mm/s change} \]

(acceptable for a demo)
Key Technologies

• Accurate laser tracking
• Adaptive optics to concentrate the energy
• High power laser and beam delivery system
• Demo system being developed at Mt Stromlo
Adaptive Optics

• Adding a high-order AO systems (with ANU)
  – For resolved passive imagery
  – Active imagery
  – Increased range
  – Remote Manoeuvre
Laser Guide Stars

- Sodium laser for AO guide star for active beam correction.
- Sum frequency generation currently ~10W
- Next stage 30W
Guide Star Laser prototype

Sum-Frequency Generator

1050 nm laser

1342 nm laser

1342 nm tunable oscillator

Amplifier #1

Amplifier #2

Amplifier #3
GSL on the telescope

- 3 planes of CF benches
- 1340, 1050nm on separate planes.
- SFG and frequency locking on third plane
- Environmental box to surround
Combining beams

- We use spectral beam combination to combine 1 x 10kW and 4 x 2kW lasers for 18 kW
- High efficiency
- Continuous operation

2kW CW fibre amplifier modules

10kW laser module
Summary

• Making excellent progress in all research programs
• Integration remote manoeuvre systems onto telescope this year with on-orbit tests to commence 2019.