LASER REMOTE MANEUVER OF SPACE DEBRIS AT THE SPACE ENVIRONMENT RESEACH CENTRE

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CONFERENCE PAPER

Active satellites have the ability to maneuver to avoid collision with other space objects. Unfortunately the majority of objects in space are debris objects that do not have the ability to maneuver. In the future the population of debris objects will grow and the probability of collision will increase. This paper will provide details on plans to use a ground based laser with uplink adaptive optics compensation to apply photon pressure to debris objects and maneuver them out of harm's way. This work is ongoing at the Space Environment Research Centre at Mt. Stromlo Australia with collaborative efforts from Lockheed Martin, Electro-Optics Systems Inc. and the Australian National University.

1. INTRODUCTION

There is no doubt that today, society strongly depends on space. Space assets provide critical communications capabilities, navigation and timing data, imagery and other sources of much needed information. Loss of space assets will lead to loss of service that potentially affects transportation, banking, medical providers, emergency response, disaster recovery and defense systems. The consistent increase in launch activities, existing operational satellites and the greater population of debris objects puts any satellite at risk for collision which may result in diminished function, full loss of capability or even destruction and the generation of many pieces of additional debris. Cases of collision are a reality. While the overall probability of collision is low and instances of collision are not frequent, they will becoming more common as the overall population of space objects increases.

A time will come when the population of space and the risk of collision are such that society will undertake space object remediation. This is far from a simple undertaking with many technical challenges and large price tags. Until that time comes, our focus will be on collision avoidance. An impending conjunction involving an actively controlled satellite can be avoided simply by altering the orbit of the satellite. It is a different story if the conjunction involves a non-maneuverable satellite, dead satellites or pieces of debris. In this case all we can currently do is sit back and watch. These types of collisions are troubling as they could potentially produce large clouds of debris increasing the probability of future collision. It has been hypothesized that this debris generation process could ultimately lead to a runaway scenario.

It has been proposed by researchers in the past that photon pressure from a ground based laser could be used to nudge objects, given sufficient warning, thus avoiding a collision. Certainly the proposed laser power levels (10 – 100 kW), projection telescope apertures (1-3 meters), tracking capabilities and adaptive optics systems exist or are being matured. Lockheed Martin, The Australian National University working with the Space Environment Research Centre in Australia are building a demonstration of just such a capability. Our objectives are to prove that the concept of laser assisted maneuver works, collect data anchoring our models, simulations and engineering tools and assess the feasibility and design of a future operational system.

2. LASER DEBRIS MANEUVER

Photons, even though they lack mass, carry momentum. Impingement of light upon the surface of an object will result in momentum transfer. Absorption of light results in a momentum transfer in a direction parallel to the direction of the incoming light. The imparted momentum due to photon absorption is the integrated laser intensity over the projected surface area in the direction of the laser beam, divided by the speed of light. Only the photon pressure normal to the surface of the object results in a force on the object. If the object were a flat plate, the force on the object is reduced by the cosine squared of the angle between the laser beam and the normal of the surface. Photon pressure due to photon reflection and thus a change in photon momentum is a more efficient method for moving an object. The resulting force on the object is twice the integrated intensity over the surface of the object, divided by the speed of light and modulated by the cosine of the angle between the laser beam and the normal of the surface. This case is more complex if the reflection is diffuse rather than specular. Surface emission due to the temperature of the object will also impart momentum, but the laser illumination is not sufficient to heat the object appreciably.

Space objects have complex shapes, varying material properties (absorption, specular reflection, diffuse reflection), change their orientation to the laser beam throughout the engagement and most likely will be tumbling. The photon pressure coefficient, Cp, describes the average object properties for the engagement. Cp ranges from 0 to 2 where a Cp of 2 represents the case of perfect reflection normal to a flat plate. One objective of our SERC program is to model and measure the distribution of Cp values for objects of interest.

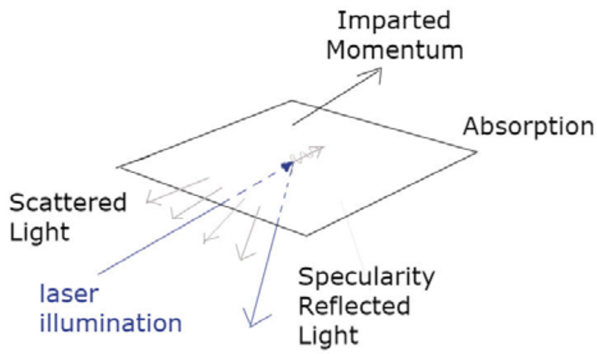

Fig. I: Reflected and absorbed laser light results in a force on an object.

A force on an object, integrated over the engagement time, will result in a velocity change. The component of the force perpendicular to the objects motion will result in a radial velocity change while the component of the force parallel to the objects motion will either increase or decrease the orbital velocity. Our modeling of this engagement has shown that there is a slight advantage, as measured by the eventual overall miss distance between objects, to illuminating the object earlier in the orbit and slowing its orbital velocity.

The force resulting from photon pressure is very small. Maximizing the intensity of the laser beam at the target will maximize the force on the object. Performance of subsystems such as the adaptive optics system is important. The velocity change is a function of the area to mass ratio of the object, therefore higher areas to mass ratio objects will be easier to move. Forecasting a conjunction early is essential. More warning time means there is the potential for engagement of the object over multiple orbits resulting in a larger velocity changes. Still, the possible velocity change is only a few centimeters per second which over multiple days results in an increase in the miss distance between two objects by 100 – 1000 meters. It is important that the parameters of the predicted conjunction be accurate for the laser assisted maneuver to have a positive effect. Given the small velocity changes, we are only considering collision avoidance. Others have proposed photon pressure to deorbit debris, but this is not in our estimation feasible with current technology. The fundamental objective of our program is to demonstrate and be able to accurately model the use of photon pressure to maneuver an object and how to do so most effectively to cause two objects likely to collide to miss each other. Studies of the most effective future network of laser sites and of the impact of moving objects in the debris population on future risk of conjunction which are not part of our studies.

3. SPACE ENVIRONMENT RESEACH CENTRE (SERC)

Australia has established a Cooperative Research Centre (CRC) to bring together international expertise from industry, academia and government to develop technologies for measurement, monitoring, analysis and management of space debris. This CRC is being operated by the Space Environment Research Centre (SERC) in Canberra Australia. Research participants include Lockheed Martin Space Systems Company, Electro-Optical Systems Inc., the Australian National University, RMIT University, Optus Telecommunications and the National Institutes of Information and Communications Technology (NICT) in Japan.

SERC has established four focused research areas to mitigate the danger posed by space debris. Research areas one addresses improved tracking capabilities as well as characterization and identification of space objects. Essentially if one does not properly know where an object is and what an object is, there is little chance of being able to accurately predict where the object will go in the future. Research area two uses the tracking and characterization capabilities developed in research area one to do the orbit determination and future orbit propagation. This technology enables more accurate predictions of future conjunctions. More importantly, that collision determination needs to be made well into the future if there is to be the possibility to mitigate the collision. Smaller changes in velocity are required if they are delivered earlier before a collision. As well, multiple engagements with the object may be possible. As the number of objects tracked increases, the challenge of predicting collisions of the many on many objects grows. SERC's third research area is addressing the computational challenges for the future environment when many more and smaller objects are in the catalog. Finally, the fourth research area is addressing the use of a laser to remotely maneuver an object if a collision is predicted. The problem must be treated as a whole. Without the advances made in research areas one through three, it would not be feasible to consider a remote maneuver of an object.

4. MT. STROMLO FACILITIES

This program is possible because most of the necessary technologies are available today and most have already been assembled by the SERC partners. The demonstration will take place at Mount Stromlo observatory just outside Canberra Australia. We will be using the 1.8 meter telescope owned and operated by Electro-Optical Systems. This telescope has the ability to track low earth orbit (LEO) objects and the pointing stability to aim and maintain an uplinked laser on these LEO objects. Upgrades to optical coatings on the smaller optics in the system are planned so higher power illuminators can be used.

Fig. II: 1.8 meter telescope at Mount Stromlo Australia.

The telescope is already operating with a natural guide star adaptive optics system. This system will be used for the laser pushing demonstration with a number of upgrades either underway or planned for the near future. These upgrades not only support the laser pushing demonstration, but are also supporting research into improved laser tracking techniques. In order for adaptive optics correction to work against a moving LEO objects, an artificial guide star will be installed on the telescope. Commercially available guide stars are currently being considered. A guide star launch telescope and optics have been designed and procurement will begin by the end of the year. Upgrades to the wavefront sensing camera have been completed and resurfacing and recoating of the deformable mirror for use with the high power laser are about to get underway.

A 10 kilowatt commercial single mode fiber laser will be used for the pushing laser. Multiple options for loan and purchase of existing laser systems are being traded. While 10 kilowatts of power is not sufficient for an operational system, current performance estimates are that this is sufficient to demonstrate against carefully chosen targets, those in the right orbit and right orbital altitude, with high area to mass ratios and of the right reflectivity. We are not attempting to mitigate a potential collision with this system, but to demonstrate feasibility of laser debris pushing and make measurements to anchor our engineering models. The SERC program is also supporting laser development with the Australian National University to deliver higher power electrically driven lasers with as good beam quality.

5. PERFORMANCE PREDICTIONS

Lockheed Martin is in the process of building up an end to end engagement model which starts at the ground based laser, models the performance of the laser and beam control system, models the propagation of the laser through the atmosphere and to the target, the laser interactions with the target and finally models the impact of the forces to the obit of the object. The performance of the beam control system, including object tracking and higher order adaptive optics and the propagation of the laser to the target is being done using Lockheed Martin's OPAL propagation code. The space object dynamics are modeled in Satellite Tool Kit (STK) with modules built in to estimate the laser interaction with the object. The effects of the laser pushing are considered in conjunction with all the other forces on the object including drag and solar pressure.

These tools are being developed to assist in optimizing the design of the system including the adaptive optics system and to aid in the design of the demonstration including the selection of appropriate targets and engagement parameters. It is the end objective of this effort to anchor these tools to data collected during the demonstration. Should laser debris pushing prove to be a viable means for controlling debris on debris collisions, these anchored models are critical in the development of the next generation of systems.

In addition to proper characterization of the optical systems, the models depend on accurate measurement and modeling of the propagation conditions above Mount Stromlo and ultimately above other sites around the world. An effort is underway by the Australian National University to measure and profile optical turbulence using a single detector stereo SCIDAR. Additional instrumentation will be employed to measure extinction and other meteorological parameters leading up to and during the experiment.

6. REMOTE MANEIVER DEMONSTRATION

The laser maneuver demonstration is planned to begin in March of 2019. Leading up to this demonstration are a successions of ground alignment and performance experiments and low power on sky experiments. We are currently working to address two challenges in this demonstration. One is the selection of an appropriate target and the other is collection of on target data including the laser irradiance and the change in object velocity. While there are many debris objects available, various requirements for the demonstration limit the selection appropriate targets. The target must be one of the lowest area to mass ratio type target in order to maximize the laser light collected while minimizing the amount of mass that must be pushed. The object needs to be above a certain altitude for which the telescope can track on the object, but not too high as to reduce the on target irradiance. The object needs to pass over the site at the right range of elevations during terminator when it can be tracked passively and preferably it should be in the right orbit so that multiple passes occur.

In order to anchor our models we require both information about the target, such as reflectivity, mass and area as well as data on the laser irradiance delivered to the target. Some of this information can be estimated, the irradiance at the target estimated from reflected light, but each of these parameters contribute errors which could be significant. We also require information about the induced change in velocity of the object. Estimating this velocity change, the primary objective of this demonstration, might be complicated if we are not able to measure range and range rates accurately from active tracking of the object or are not able to obtain sufficiently accurate down range tracking data.

For these reasons, we are currently considering the launch of one or more cubesats to serve as instrumented targets. The objects will be completely characterized prior to launch so we understand their reflectivity, their area, mass and their dynamics. We will select orbits, likely sun synchronous orbits, which will bring the target regularly over the site during terminator at altitudes high enough to be tracked by the telescope yet low enough that we are able to put sufficient irradiance on the target. The objects will be equipped with retro reflectors which will allow them to be accurately tracked and ranged for better estimations of any induced velocity changes. The objects will be instrumented to measure laser irradiance directly which is very important not only for the anchoring of our performance models but also useful in testing and optimizing the performance of the beam control system, especially the adaptive optics system. We are also looking at equipping the targets with deployable structures such as balloons or drag chutes which will greatly increase the available target surface area. The data from these cubesats would not only support the efforts in the laser maneuver experiment but would also support data collection opportunities for the other SERC research efforts.

7. SUMMARY

Mitigation of debris on debris collisions in the future may be necessary to limit the growth of the space population and the hazard to space operators. The use of ground based lasers to apply photon pressure to debris objects, perturbing their orbits and avoiding a potential conjunction may be a viable means for managing these conjunctions. Lockheed Martin and our other SERC collaborators will demonstrate the feasibility of this approach and collect data necessary to anchor models at the Mount Stromlo Observatory over the next few years. We are considering an expansion of the effort to include the development of one or more cubesats as surrogate instrumented targets.

8. REFERENCES

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