Tracking orbital debris in a busy airspace environment (3115).

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Abstract:

With the amount of orbital debris increasing dramatically, the development of methods to remove the debris or predict its future impact to other orbital assets is becoming critical. The first step in either effort is to develop the ability to accurately locate and track the debris. Ground based laser ranging can provide more accurate position information than current radar systems and by using multiple stations to track the same object, accurate orbits can be obtained. In this scenario the more stations participating in the effort, the more accurately and reliably the orbit can be defined. However, stations in areas where the airspace is crowded are limited in the amount of laser power they can use to track such objects without endangering passing aircraft. To reduce these effects we examine the design implications of shifting the laser wavelength from 0.532 μm or 1.064 μm, the standards for laser ranging, to the 1.5 μm range where more powerful lasers can be used without generating safety concerns. We examined the trade space of the amount of eye safe power at different wavelengths, combined with link analysis of a sample target and the efficiency of the receive detectors to the returning signal. We found that by switching to wavelengths around 1550 nm from 532 nm, we could increase the laser power by a factor of 1000 while remaining eye safe. In addition, the eye safe 1550 nm would generate about a factor of 2 improvements in returns over that of a system successfully using non eye safe powers in the 532nm wavelengths.

Introduction

The amount of debris in orbit is already causing concerns for active satellites, including the International Space Station, by increasing the numbers of maneuvers required to avoid collisions[1)]. This situation is predicted to worsen over the next few decades as larger pieces of debris are impacted and create more and more smaller pieces. Generating orbital predictions for collision avoidance or remediation can be greatly improved by highly accurate positioning and tracking of the debris, which has been demonstrated using satellite laser ranging (SLR) techniques by several SLR stations including Graz[2)] in Austria. Most of the work done to this point has used relatively high power lasers with a 532 nm wavelength. The high power creates risks for aircraft and active satellites if they pass through the beam being used to track the debris. One way to reduce the risk is to shift the wavelengths into infrared (IR) wavelengths, but doing so may affect other aspects of the process like the efficiency of the detector, limiting the overall tracking ability. In order to estimate the overall effect we have performed a "link analysis" type study looking at the system as a whole using the Graz SLR system for comparison.

Eye safe laser power

Any laser operating at a power low enough to not cause damage to the human eye in the amount of time required to react (i.e. by blinking) is considered "eye safe". In regions with a large amount of air traffic, operation at less power than the eye safe limit means fewer interruptions in tracking and safer overall operations. Since the human eye reacts to longer wavelengths less efficiently, longer wavelengths can be operated at higher powers safely. To determine the power level at which different wavelengths are still considered eye safe we used "LHaz 6.0" software maintained by the United States Air Force (USAF). This program takes as inputs the laser wavelength, spot size, divergence, distance, frequency and pulse width to calculate the amount of attenuation needed at the target to be eye safe by the current standards under American National Standards Institute.

Since so much of the calculation depends on the particulars of the station, the important take away from this effort is the relative amounts of power needed to reach the eye safe threshold. Table 1 below shows the amounts of power which can be used and still be eye safe for 532, 1064 and 1550 nm based on a set of parameters for the telescope which remains constant for all calculations. Other stations with different parameters (like telescope area) will have different absolute values for the three wavelengths, but the ratios should remain constant. The end results is that 1550 nm wavelengths are considered eye safe at 100x the power of 1064nm and 1000x that of 532nm.

Wavelength	**532 nm**	**1064 nm**	**1550 nm**
10 sec exp.	0.0001 J	0.001 J	0.982 J
0.25 sec exp.	0.0001 J	0.001 J	37.767 J

Table 1: Eye safe power levels as determined by USAFs LHaz 6.0 software for three different wavelengths and two different standards of exposure time. For this study we used an arbitrary telescope with 25 cm diameter, 50 Hz rep rate, and 1 ns pulse width.

Surface reflection

Since debris in general does not have corner cubes to reflect the incident light like the geodetic satellites used for SLR, the return will depend on the reflection from surface material. We looked at some likely materials for debris composition and how the reflectance of the material changed with respect to wavelength (table 2). In all cases the reflectance increases as the light moves to longer and longer wavelengths. While in most cases the difference in reflectance is small, moving to 1550 nm from 532 or 1064 nm will not decrease the amount of light reflected from the debris.

Wavelengths	**532 nm**	**1064 nm**	**1550 nm**
Gold	~70%	~98%	~98%
Aluminum	>90%	>95%	~98%
Silicon	~35%	~30%	>40%

Table 2: Reflectance at different wavelengths for some common materials

Detector Quantum Efficiency (QE)

An important part of laser ranging is the detector. Since the returns are typically low energy, single photon detectors are employed, for which the efficiency of converting incident photons into a measureable signal is expressed as a percentage called the Quantum Efficiency (QE). The QE of the detector depends on, among other factors, what the material is made of and the wavelength of the incident photon.

In order to make a comparison in detectors for this study we looked at the published QEs for single photon detectors for commercially available products. Since no single detector responds to the entire spectrum under consideration we looked at a silicon avalanche photo diode (Si APD) for 532nm and an Indium Gallium Arsenide avalanche photo diode (InGaAs APD) for 1550 nm. The results are shown in table 3. From the table we see that while the QE attainable for 1550 nm is less than the QE attainable for 532 nm, it is within an order of magnitude (about a factor of 7 lower).

Wavelengths	**532 nm**	**1064 nm**	**1550 nm**
Si APD	~70%	~5%	Neg.
InGaAs APD	Neg.	<10%	~10%

Table 3: A comparison of the QE for two commercially available detectors at three wavelengths

Link Study

The link study shown in table 4 below (following page) compares a successful debris tracking effort by the Graz SLR station using a 532 nm laser and a proposed experiment at the Goddard Geophysical and Astronomical Observatory (GGAO) using a 1557 nm laser. Other than the different laser wavelength a major difference between the two systems is the size of the telescopes, Graz having about a factor 10 less effective area. Another important difference is that the Graz system is not operating within eye safe power levels for 532 nm, while the GGAO system is proposed to be working within eye safe power levels for 1557 nm.

With the larger telescope the GGAO system would likely see a factor of 12 better return rates at an eye safe power level, when compared directly to the non-eye safe power levels of 532 nm at Graz. A better metric of the improvement seen would be to express the return rates per unit area of the telescope to determine an advantage at an arbitrary system. Appling this metric shows the GGAO system with return rates of 0.291 photons/m2 while the Graz system has 0.138 photons/m2. Thus switching to 1557 nm from 532 nm should allow for greater than a factor of 2 improvements in return rates (per unit area) and at the same time allow the system to operate with eye safe laser power.

Conclusions

The need for high laser power in tracking orbital debris increases the risk to aircraft, particularly in areas with a high volume of air traffic. A possible answer to the problem is shifting to IR laser wavelengths where higher laser powers remain eye safe. Lasers in the 1550 nm range are considered eye safe at 100 to 1000 times the power for more traditional SLR wavelengths of 1064nm and 532nm. In general the performance of 1550 nm wavelengths is about the same or slightly better than shorter wavelengths with the exception of the detector QE. But even the detector QE for 1550 nm is within an order of magnitude, which is more than offset by the gain in power. A direct comparison between a proposed 1550 nm wavelength system with the Graz SLR stations system for debris tracking shows that by switching to 1550 nm any given station can increase the return rate by a factor of about 2 and at the same time achieve ranging using eye safe power levels.

References

1) "Instability of the Current Orbital Debris Population", N. Johnson and J.-C. Liou, Orbital Debris Quarterly News, April 2006, Vol. 10, Issue 2
2) Kirchner, G., et al. Laser measurements to space debris from Graz SLR station. J. Adv. Space Res. (2012),http://dx.doi.org/10.1016/j.asr.2012.08.009

Lidar sensing assumptions & parameters	**Proposed NASA/GSFC**	**Austria/GRAZ 2013**
Lidar Transmitter Parameters:		
Transmitter Wavelength (nm)	1557	532
Photon Energy (J)	1.28E-19	3.74E-19
Laser output pulse energy (J)	0.400	0.200
Transmitter optics transmission	0.90	0.90
Launched Pulse Energy (J)	0.36	0.18
Laser pulse-rate (Hz)	50	100
Launched Pulse Power (W)	18.00	18.00
Launched beam divergence effective diam. (microradian)	50	50
Target Link Assumptions		
Range to target (km)	1,000	
1-way Atmospheric transmission	0.6	
Target cross-section diameter (m)	0.5	
Area of target surface (sq. m)	1.96E-01	
Area of transmitted beam at the target range (m)	1.96E+03	
Fraction of beam reflected	1.00E-04	
Diffuse Surface Target reflectivity	0.1	
Target backscatter coeff. ((fraction*reflectivity)/ster)	3.18E-06	
Receiver Parameters:		
Telescope Diameter (m)	1.2	0.5
Telescope Central Obscur. (m)	0.3	0.1
Telescope Area (sq. m)	1.060	0.188
Receiver System optics transmission	0.5	0.5
Receiver time gate duration (microsec)	10	10
Detector Parameters:		
Detector material and type	InGaAs APD geiger mode	SiAPD geiger mode
Detector Photon Detection Efficiency	0.18	0.5
Detector Dark count rate (/sec)	30,000	10,000
# of Detector Dark Counts in Integ. Time	0.30	0.10
Received mean signal (photo-electrons) per transmittted pulse	**0.308**	**0.026**

Table 4: Link study comparison between existing Graz system using a 532nm laser at non-eye safe powers and proposed GGAO system using a 1557 nm laser at eye safe powers.