MICROSATELLITE FOR ORBITAL DEBRIS DETECTION BY LIDAR

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Abstract

Medium-size orbital debris are difficult to monitor from the Earth. It is thus interesting to use in-orbit measurements. To that purpose the LIDAR is a good candidate system to perform this detection. A way to efficiently evaluate the debris detection by LIDAR is to compare the effective detection suface with the one of other available detector type.

Introduction

The presence of numerous small and medium-sized debris in near-Earth orbit creates a hazard for low-orbiting (manned and unmanned) spacecrafts. Until recently, there was no confirmed instances of orbital debris seriously damaging or destroying a spacecraft ([1]). However, the recent example of the French CERISE microsatellite, damaged by such a debris, illustrates this increasing danger. Debris on Low-Earth Orbit (LEO) which size are greater than 10-50 cm can be monitored from the Earth on a routinely basis. This range of trackable sizes naturally increases with the orbit altitude (at GEO, the minimum trackable size is of the order of 1 meter). Unfortunately, serious or even catastrophic damage can also arise from smaller debris (1 mm - 10 cm) due to the high relative speeds on their orbits ([2], [3]). Furthermore, such debris cannot be adequately tracked from the ground on a continuous basis.

It appears therefore necessary to find operationnal means to assess the spatial distribution and the behaviour of such debris in LEO. Numerous methods have been proposed to that effect. SAGEM S.A. proposes to study the feasability of operating a LIDAR on board an orbital platform to carry out a global survey of debris around its orbit.

We propose to use a small satellite on a low elliptical polar orbit and a LIDAR for the detection of debris by backscattering. The data acquired by this detector will then be regularly transmitted to a ground station. Such data encompass spatial location of the debris at the time of their detection, as well as their radial velocity and estimated size. The aim of such a demonstration satellite would be to assess the feasibility of such measurements and to provide a first statistical sampling of small and medium size debris data in LEO.

This paper describes the expected performances of such a demonstration satellite, and presents the acceptable trade-offs as a function of the input parameters (size of the debris, orbit altitude, etc), in terms of measurement duration, detection limit distance, instantaneous equivalent detection surface.

1.Experimental setup

Lidar description

LIDAR ([4]) detection is similar to radar in the optical wavelength domain. The measurement principle is to use a narrow-beam light pulse emitted by a laser.

The purpose of this equipment is to increase the detectability of small debris. The experimental setup is a trade-off between the detection accuracy (in term of range and Doppler shift), the effective detection surface and the field of view.

The main idea of this particular design is to maximize the equivalent detection surface of the LIDAR.

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This design is to be compared with the classical impact surface detector type which are constituted most of the time by a shocks sensitive surface. These detectors can detect the number and the energy of eachshocks and even the direction of impact.

A LIDAR detector can be advantageously compared with this type of detector. The principle parameters are: the instantaneous detection surface, the repetition rate and the minimum size at accessible range (for an expected reflectivity factor).

The detection surface is determined by the following relation:

$$S = \frac{rm}{rr.c}\left(\int_{ri}^{rm} \pi.D(r)dr + \frac{1}{8}\pi\left(D(ri)^2 + D(rm)^2\right)\right)$$

where *rr* is the repetition rate,

rm is the accessible range,

ri is the minimum range,

D the diameter of the laser beam.

Given that the values chosen for the mean detection surface depend on the maximum accessible range and the repetition rate, the optimal ratio $\frac{rm}{rr.c}$ is equal to 0.5 .

Hence,the maximum detection range for a given debris diameter is:

$$rm = .167\,\frac{p^{\frac{1}{4}}.a^{\frac{1}{4}}\sqrt{dd}\sqrt{dia}}{n^{\frac{1}{4}}\sqrt{\tan(dv)}}$$

Where: *p* is the mean power of the laser,

a is the mean reflectivity factor,

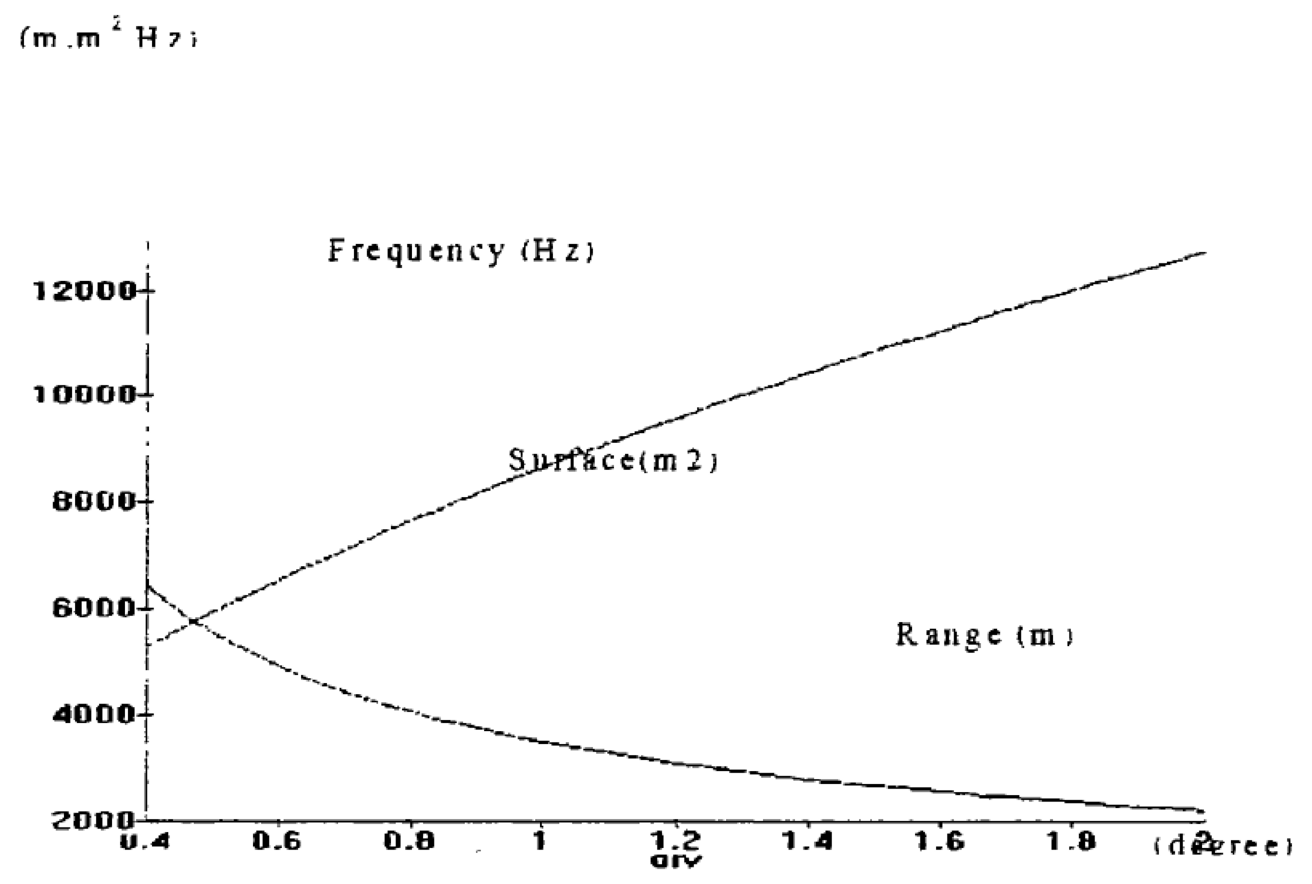
dd is the debris diameter,

dia is the photon collector,

n is the detection level,

dv is the laser beam divergence.

The following curves show clearly that the debris detection trade off is linked to the actual laser specification regarding the repetition rate the pulse width and the mean power.



Parametric curves showing the variation of the repetition rate, the maximum accessible range and the effective detection surface

Hence, the achievable detection surface is about 1000m^2 for a 1Km range. The most adapted laser for this type of lidar seems to be a classical YAG type with 10Khz repetition rate (rr), 30ns pulse width (dti) and in the mJ class energy.

The Doppler shift can be optically detected and processed using a multichannel analyser to cover the possible range of radial velocities.

With this design a system with 10 classes of doppler echoes is envisaged. If one accounts for velocities in the range -20 km/s to 20 km/s compatible with expected or measured values (see for instance [5]), the single class width will thus be 4 km/s.

The spatial resolution is better than dti.c. (ie:3-30m)

The cost of this lidar is driven by the detector type and the telescope diameter. The cost foreseen lies between 2 and 3MAU.

2. Choice of the platform

In order to assess the feasability and the designing of a lidar detector for in-orbit debris measurement. it is of major interest to use a low cost and quick access to orbit. The platform developed for this application can be in the microsatellite class which means that the overall mass of the plateform will be under 150 Kg. It can be launched as a piggy-back payload on high rate launch booster such as SOYOUZ, COSMOS or PROTON.

Molnya type orbit are interesting because of the elliptical characteristics of the orbital parameters. A SOYOUZ type booster with the MOLNYA upper stage is a good candidate for this technological payload.

The mission duration is dependent on several factors but should not be below one year in order to acquire sufficient experimental data

The overall cost foreseen is should be under 20MAU launch included.

The design is constrained by the size of the collecting mirror as well as by the required electric power. As a matter of fact it is clear that the photon collecting surface is a key parameter for the performances of the detector.

These constraints lead us to opt for a solar oriented platform with a 0,3 meter diameter mirror. The mirror does not have to be a high optical quality because it acts only as a photons collector. The size of the solar panel is directly linked to the mean power of the laser. The present trade-off account for two solar panels of an overall surface of 1 m^2 surface.

The attitude and orbit control system make use of an hybrid gyroscope manufactured by SAGEM coupled to reaction wheels and magnetotorquers for the attitude control along with a GPS sensor to determine the orbital parameters.

Hindrances

The major difficulty is the jamming effects of environmental sources as earth, moon, planets, stars, big artificial satellites.

An helping factor for the natural antijamming properties of the detector is the narrow band interference filter which will perform the Doppler classification of the encountered debris.

However, the main idea to solve these difficulties is to take into account the orbital determination of the detector along with the precise line of sight of the detecting telescope. These considerations lead to the following carateristics of the AOSC which are: 0.1° attitude and 30m orbit determination.

Furthermore in order to limit the jamming effects of the sun or the earth it is recommended to choose a quasi zenithal line of sight. This choice stay compatible with in-orbit detection of particles.

Conclusion

The aim of this demonstration satellite is to assess the feasibility of a LIDAR detection method for debris in the size range 1 mm to 10 cm, on a "routine" basis. Parameters such as radial velocity with respect to the detector and distance to the Earth would be provided in a band of 1 to 10 km around the orbit of the satellite. A constellation of small satellites carrying such devices may even provide additional orientation and orbital data for these debris. This assessement suggest that synchronised clustered microsatellite constelation could be studied in order to provide full tracking parameters. An other option would be to develop a dual system of LIDAR operating simultaneously on a single platform to provide for parallaxe measurement of debris.

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