LASER ALTIMETER FOR A MICROSATELLITE

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This paper discusses a laser altimeter conceived for the autonomous correction of stereoscopic image pairs acquired by the high-resolution camera of a microsatellite.

1. Introduction

SMART (Scientific Microsatellite for Advanced Research and Technology) is the first Italian example of university satellite (mass: 50 kg, available power: 10 W, size 45×45×37 cm, altitude: 400 km) [1]. SMART has been designed for scientific and educational purposes and can be applied to various missions. Recently, due to the growing importance of high resolution Earth observation from space, the study of an optical extension of the payload (including a 35 cm diameter telescope) has been undertaken. In the framework of such development, this communication discusses the further implementation of a laser altimeter. This latter extension is rather simple (the aforementioned telescope can be used as receiver) and complementary information will be gained, in addition to that contained in Earth images (stereoscopic model calibration).

2. Laser altimetry

Laser altimetry is gaining importance in the accurate profiling of our planet and even other astronomical bodies (the Moon, asteroids and Mars). Nevertheless, the usual correction of stereoscopic image pairs is performed using a great number of reference ground control points, with a considerable increase of cost and manpower.

A laser altimeter is essentially composed of a transmitter (laser) and a receiver (telescope). The laser emits a light pulse toward the planet and the telescope observes the fraction backscattered by the surface. Its principle of operation is conceptually simple: the planet surface at the distance R from the system sends back part of the laser pulse toward the telescope. Consequently, the analysis of the detected signal as a function of t, time interval between emission and detection, allows one to determine the distance.

The following requirements of the laser altimeter for a microsatellite can be assessed:

a) Objectives:

The laser altimeter for SMART should achieve the following objectives:

- accuracy in the measurement of the satellite altitude of some m, enough for the calibration of the stereoscopic model,
- power consumption of some W, compatible with the available power of SMART.

As regards the first request, we note that the accuracy depends on the atmospheric extinction. In order to comply with the second request, we will consider a transmitter based on a miniaturized pulsed diode-pumped Nd:YAG laser (Table 1).

Table 1 Specifications of the transmitter of the laser altimeter for SMART.

Pulse repetition rate	1 kHz
Pulse energy	1 mJ
Beam divergence	100 μrad
Pulse duration	10 ns
Wavelength	1064 nm

b) Atmospheric model and altitude error

An atmospheric model is necessary to analyze the extinction of the laser pulse in its round trip. In particular, we must simulate the molecular density (Fig. 1) and the aerosol extinction coefficient (Fig. 2) as a function of altitude. Fig. 1 is a model of the molecular density (average on one-year and all latitudes).
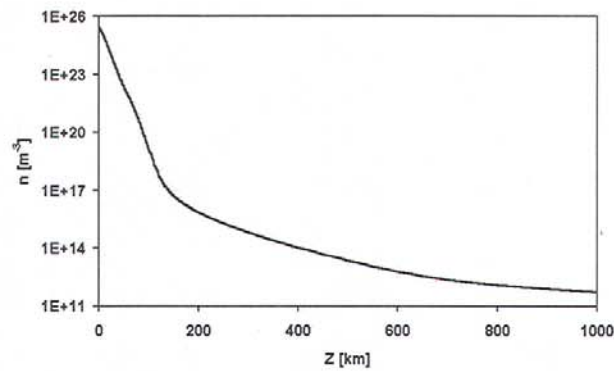

Fig. 1. Model of the molecular density as a function of the altitude.

Fig. 2 is a model of the average aerosol extinction coefficient: as one can expect, the aerosol load is maximum near the Earth surfaces and decreases as a function of altitude. Both models have been developed by the US Air Force on the basis of many-year measurements [2, 3]. In our case, referring to those classical works, we have obtained the value of 0.7 for the overall average atmospheric transmittance. Let us recall that the molecular extinction coefficient is given by the molecular density multiplied by the Rayleigh cross section [4].
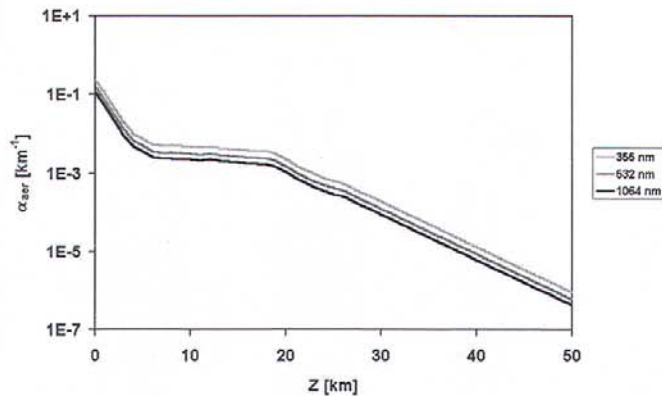

Fig. 2. Model of the aerosol extinction coefficient as a function of the altitude for three relevant wavelengths.

The error in the measurement of the satellite altitude (e_R) depends on the laser pulse duration (T), the bandwidth of the detection electronics (B) and the signal-to-noise ratio (SNR) [5]:

$$e_R = \frac{c}{2} \sqrt{\frac{T}{B\,SNR}} \tag{1}$$

Concerning the signal-to-noise ratio, in the common case in which the signal fluctuation dominates on the other sources of noise and the Poisson statistic [6] can be applied, we can write:

$$SNR = \sqrt{\frac{E\,\lambda}{h\,c}}, \tag{2}$$

where E is the detected energy, λ is the wavelength and h is the Planck constant. The detected energy can be calculated from the radar equation [5]:

$$E = E_0 \frac{\alpha\,D^2}{16\,R^2} \eta\,\tau, \tag{3}$$

Where E_0 is the energy of the transmitted pulse, α is the albedo of the Earth surface, D is the receiver diameter, η is the system efficiency and τ is the atmospheric transmittance.

If we replace the aforementioned values (section 1 and 3, Table 1) and the following reasonable parameters:

$B = 100$ MHz,

$\alpha = 0.1$,

$\eta = 0.4$,

in relations (1), (2) and (3), we obtain:

$e_R = 0.3$ m,

assuming to average the signal over 100 laser pulses (corresponding to 0.1 s of operation, that is about 700 m covered by the satellite nadir). Even though the approximations made are quite rough and in the pessimistic assumption that the accuracy has been underestimated by a factor of 10, an error in the measurement of the satellite altitude around some m seems achievable by the laser altimeter described here.

c) Optical and electronic requirements

The transmitter and receiver of the laser altimeter must be accurately aligned to obtain correct measurements. In order to make easier this task, the system should be conceived in monostatic configuration (the transmitter and receiver axes coincide). Moreover, an automatic control of the alignment [7] could be implemented by means of two micrometric actuators controlled by a microprocessor.

As we have seen, the error in the measurement of the satellite altitude depends also on the bandwidth of the detection electronics. Moreover, the time-to-digital converter (TDC) should have a high resolution, corresponding to the altitude error. In case the error in the measurement of the satellite altitude is about 1 m, we can deduce that the TDC resolution must be at least of about 7 ns, in order to avoid the introduction of another source of incertitude. In fact, 7 ns correspond to a pulse round trip of 1.05 m. A resolution of about 7 ns is achievable with current TDC boards.

The laser beam pointed toward the Earth surface poses a safety problem for the eye of a possible observer. If the transmitter characteristics are according to the values of Table 1, the beam has a cross section of about 40 m in the troposphere. Even assuming no atmospheric extinction, this corresponds to an exposure lower than 1 μJ/m^2, which is over 50,000 less than the maximum permissible exposure [8].

In conclusions I thank to usual models of atmosphere and signal-to-noise ratio, the error in the measurement of the satellite altitude has been estimated to be about 1 m. This is a remarkable result for a miniaturized instrument, especially if compared with large laser altimeters: NEAR (Near Earth Asteroid Rendezvous, launched by NASA at the beginning of 1996), for instance, has an accuracy of 6 m.

If we remember that the laser altimeter will be coupled to a high resolution camera, we conclude that SMART could provide corrected stereoscopic images of the Earth surface without the need of reference ground control points: the correction of the systematic error of stereoscopic image pairs (stereoscopic model calibration) would be offered by the laser altimeter.

References

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