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Abstract: This work is directly related to the development of the laser altimeter for the ASTER mission, named ALR. The Brazilian deep space mission ASTER plans to send a small spacecraft to encounter and investigate the triple asteroid 2001-SN263. The launch is scheduled to occur in 2017 and the ALR is now under development in partnership with UNICAMP, UFABC and aerospace companies. In this work, the environment and the operation of the instrument were modeled and simulations were carried out in order to better understand and define the instrument parameters. The creation of the simulation software to control the operation of the instrument was the main purpose of this work, and the software so far created is the main result of it. The software was successfully tested with respect to some common expected situations.

Keywords: Laser altimeter, ALR, laser rangefinder, aerospace technology, Brazilian deep space mission, ASTER, asteroid 2001SN263.

1 – Introduction

Asteroids are primordial celestial bodies that can help scientists to understand the process of formation of the solar system. NEAs (Near Earth Asteroids) are especially interesting objects to investigate in space missions with robotic probes, since they periodically approach the Earth's orbit and eventually may threaten life on the planet.

In the first decade of the 21st century, a new era in space exploration began with the advent of spacecraft observations of asteroids. In 2000, the NEAR spacecraft went into orbit around the asteroid 433 Eros for a year of scientific investigation of its geology, mineralogy and surface chemistry [1, 2]. In 2005, the Hayabusa spacecraft arrived in its encounter with asteroid Itokawa for scientific observation of the asteroid shape, spin, topography, composition and density, and subsequent touchdown, sample collection and return to Earth [3, 4]. Both spacecrafts were equipped with a laser altimeter for navigation and topographical purposes [5]. Basically, such an onboard instrument is used to determine the elevation from the spacecraft to a given location on the surface of the asteroid by simply measuring the time delay between the transmission of a laser pulse and its return.
Space missions designed to investigate asteroids have become more important, mainly after the increasing interest in the mining of such bodies, where various minerals and water could be extracted. An example of a future mission to asteroids is the mission Hayabusa 2, whose possible launch window is in 2014 or 2015, with arrival in the asteroid named 1999JU3 in 2018, and return to Earth in 2020 [6]. In Brazil, laser altimetry for space missions is a new branch of research and development for engineers and scientists whose interest in this sector has grown as the country plans its first ever deep-space mission [7, 8].

Based on science and technical advisory reports conducted recently by Brazilian experts at universities, research centers and private companies, Brazil government has now recognized the importance of an ambitious deep-space mission in order to test key national technologies in space, to burst the national aerospace industry and also to stimulate the new generation of space scientists and engineers of the country.

2 – ASTER, A Brazilian Deep Space Mission

The ASTER mission is the first time Brazil is involved in a deep space mission. To explore the unknown triple near-Earth asteroid 2001-SN263, the mission will be undertaken in cooperation with Russia.

The ASTER mission spacecraft is based on a Russian MetNet platform. Its launch is scheduled to occur in 2017. The scientific instrumentation to fly will collect asteroid data for approximately 1 year and the main scientific objectives include determining the size, mass, volume, gravity field and rotation of the triple asteroid members, together with the identification of the composition, morphology and topography of the surface of each body. An investigation of the system dynamics will be conducted to obtain evidences of the system formation.

UFABC participates in this mission with the development of two instruments that will be used in the investigation of the asteroids, a laser altimeter, named ALR, and an infrared spectrometer.

The ALR (Aster Laser Rangefinder) will be useful in the navigation of the probe, in the phase of the mission when the spacecraft shall be maneuvered to reach a closer approach to the asteroid, as well as in the investigation and mapping of the asteroid features to be conducted in the proximity phase [9].

A laser rangefinder is a tool that works from the emission of laser pulses toward a specific target and the reception of the return signal reflected by the target surface. The measurement of the pulse time of flight allows calculating accurately the distance between emitter and target. Additionally, when the expanded pulse illuminates a small area of the target surface, the return pulse brings the information about the topographical features of the surface illuminated by the pulse. The continuous emission of pulses, combined with the probe-target movement, enables the evaluation of the whole surface, and by interpolation, the characteristic topography of the investigated body can be determined. The investigation of the target is conducted track by track. Reviews of data on tracks result in a topographic model of the target revealing its surface characteristics. Interpolations are used to estimate the areas not covered by the pulses between tracks.

3 – Methodology: Principles and Operation Parameters of the ALR

The topographic details of the area illuminated by a laser pulse, in this case the asteroid 2001-SN263, are obtained through the analysis of the received waveform. The asteroid surface is normally irregular and there are some common topographic features expected to be detected. Among them, the four simplest ones are: cliff, flat surface, inclined surface and depression, which have been analyzed in the literature [10]. Although other types of surface terrains were also subject of modeling and
simulation, in this work, only the cliff type is described in detail and has its results presented, because it has two different possible well known results that can be used to verify the modeling and simulation process.

It is important to note that the waveform of the pulse received by the detector depends on the waveform of the emitted pulse, the topographical features of the surface and the way this surface reflects the emitted light (a diffuse reflection model was used). On the other hand the intensity of the received pulse depends on the intensity of the emitted pulse, the beam divergence angle, the distance between the instrument and the asteroid, the absorption of the environment where the light propagates (called the environment transmissivity), the aperture of the detector telescope, and on the specific reflectance of the surface with respect to the incident laser frequency. The results reported here were obtained through modeling software, considering all these intervening variables.

When the laser pulse is emitted and the footprint covers the entire length of a cliff, there are two expected waveforms for the return pulse, which can be seen in Figure 1.

![Figure 1: Types of cliff and the expected return pulses.](source)

Source: Marti, Kilian. The BepiColombo Laser Altimeter - Detector Characterization and Implications for Mercury Science. Bern University. 2005.

If the pulse center is shifted toward a plain, the reflected pulse is split into two components with different intensities, because most of the intensity is emitted at the lower topography and take longer to be reflected.

If the center of the laser beam focus exactly at the point of variation in altitude between the surfaces of the cliff, the two components of the reflected pulse will have identical intensities because the intensities will also be distributed on the cliff, differing only about in the time of reflection.

### 4 – Results: Simulations and the ALR Control Software

The simulation of the return signal was performed with use of the MATLAB® environment [11]. The various parameters and modeling details will be the subject of another paper. It was expected to obtain the return waveforms found in the literature [10].

The use of the simulation software made it possible to simulate the emission of a laser pulse, the consequent target surface illumination (initially using the cylindrical “flat hat” spatial energy distribution model), the pulse reflection on the target surface (cliff), its return (after reflection) and detection with the registration of the return waveform. The simulation software was implemented considering the surface illuminated by the laser beam as a diffuse light-emitting surface, divided into four quadrants of multiple tiny light sources (Figure 2).
The axes in meters. In this simulation, each source has $2 \times 2 \text{ cm}^2$ area, the divergence angle is $800 \, \mu \text{rad}$ and the distance target-instrument is $1,000 \, \text{m}$.

In the implemented algorithm, the width of the laser pulse was standardized in 10 ns, a common pulse width found in the literature \[5\]. In general, the pulse width is identified at the half power of the emitted pulse (FWHM - Full Wave Half Maximum).

The specifications for the laser beam used in the simulation were taken from the literature \[12\], including those related to the ALR under development \[9\].

Initially, simulations were performed using a square wave as emitted pulse. Subsequently, the trapezoidal shape of the emitted pulse was used. This choice was taken because this second option better describes the actual case. Other shapes for the emitted pulse are also available and will be discussed in a future work (exponential and Gaussian).

The simulations described here were performed on surfaces shaped so as to present an altitude difference between two regions characterizing a cliff. The two situations shown in Figure 1 are considered. The altitude differences among the four quadrants (Figure 2) are manipulated by the user, thus changing the expected shape of the return wave.

One important parameter to be considered is the sampling time, i.e., the time interval used to integrate all energy reaching the detector sensor. This time is chosen according to the instrument objectives and is directly related to the desired vertical resolution. The use of a detector capable of sampling the return wave every 1 ns, as done here, means that the register of a full return waveform is wanted and that the vertical resolution of 15 cm was required. To provide such a sampling time, an oscillator of 1 GHz has to be used. The simulator developed is being used as a helpful tool in the analysis and choice of the pair detector-oscillator to fly in the ASTER mission. This choice, of course, has to take into consideration the best cost-benefit relation.

As one of its outputs, the simulator offers a graph of the detected return pulse. The results of the first simulation are show in Figure 3. In this case, half of the pulse energy reaches the relief with highest altitude (distance target-surface 1,000 m), and the other half reaches the surface with lower altitude (distance target-surface 1,003 m).
Figure 3: Emitted laser pulse function (trapezoidal; left), and its characteristic return wave (right).

In the first simulation, two waveforms are obtained in return with practically the same power, as shown in Figure 3 (right). The intensity of the return signal is very low, of the order of nW ($10^{-9}$ Watts). This expected result is consistent with literature [12] and shows clearly the need of signal amplification. The two separate waves are due to the fact that the altitude difference between the two surfaces is bigger than half of the distance the light travels during the pulse emission time interval, for the parameters used. That is, when the photons reflected by the most distant surface return to the instrument detector, all photons reflected by the closest surface have already arrived and were detected nanoseconds before, causing the observed interval between pulses in the return waveform. An observation is made here about the slight difference in power intensity seen in Figure 3 (right) that is due mainly to the diffusion of the light coming from the reflection on the second surface (3 m more distant). The intensity of the light reaching the detector is inversely proportional to the square of the distance source-detector. Also, the environment absorption of the travelling light has been considered.

Figure 4: Return waveform of the second simulation. Obtained during the simulation on a surface Cliff with 30cm of difference between the surfaces. 1/4 of the pulse reaches the relief with highest altitude and 3/4 reaches the surface with lower altitude.

The results of the second simulation are shown in Figure 4. The emitted pulse is the same as in Figure 3. Here, 1/4 of the pulse reaches the relief with highest altitude and 3/4 reaches the surface with
lower altitude. The graph obtained confirms the expected shapes, time intervals and power intensities, according to the cited literature, thus verifying the adequacy of the developed software.

5 – Conclusions

Several simulations were performed, initially starting with a square wave pulse and subsequently with use of a trapezoidal wave, which is closer to the real case and whose results were presented. In both cases, the simulations showed results very close to those expected in the literature, proving the functionality of the software.

The main motivation for the creation of the laser altimeter simulator, described partially here, is the development of software to control the operation of the ALR, the laser altimeter to fly in the Brazilian mission to deep space – ASTER.

The software simulator is still under development at UFABC. Many of its modules will be used in the control and processing unit that accompanies the apparatus as a whole. It is now being improved to contain more specific modules (different choices for the emitted pulse function, for instance), and to include the processing of the return wave pulse. Also it has been used as a tool to better define instrument parameters and parts.

6 – References

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