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Tool for Planning Radio Scattering Experiments from Planetary Surfaces with Orbiting Spacecraft

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Abstract

Spacecraft orbiting solar system bodies with a radio link to receiving stations on the Earth can carry out a class of radio science experiments commonly called bistatic radar (BSR). Radio signals from the spacecraft, incident on the target's surface near the Brewster angle, are changed during the reflection process. Careful analysis of the echo characteristics -especially the Doppler dispersion and polarization- allows inference of surface slopes and dielectric constant of the surface material on scales comparable to the wavelength. A new software tool has been developed to plan such surface scattering experiments with the Dawn spacecraft at Vesta and Ceres. We present the theory and methodology behind the algorithm and example products.

1. Introduction

For the upcoming NASA Dawn mission a method of studying planetary surface scattering, based on Bistatic Radar (BSR), has been proposed. Dawn begins exploring its first target, Vesta, in summer 2011.

Bistatic experiments, in which the transmitter and the receiver are separated, have been conducted over celestial bodies, such as the Moon [1] and Mars [2], to estimate the roughness of the planetary surface, while also providing a measure of the surface dielectric properties, according to Fresnel equations [3]. Separating the receiver avoids incorporating full experiment complexity in the spacecraft: instead, the spacecraft radio transmitter and Earth-based receiving stations can be used. Such bistatic observations are conducted as downlink "experiment of opportunity" and, for the Dawn mission, allow a further investigation of the target surface to be carried out without any significant supplementary cost.

Geometry is the principal distinguishing feature of bistatic experiments. So far, bistatic experiments have been mainly conducted for spherical targets: to the authors' knowledge a comprehensive method of solving more complex bistatic planetary geometries has not been fully developed. With regard to Vesta, problems arise because of the extremely irregular shape of the asteroid.

A new software tool has been developed to overcome such difficulties. The following sections show how the software works, and outline the mathematical theory behind the algorithm.

2. Software development

The fundamental problem which underlies the planning of BSR experiments is determining how the transmitted signal reaches the receiver via reflection from the target. That is, once the experiment time has been selected, we want to know how the transmitting antenna on the spacecraft should be oriented.

2.1 The light-time problem

The positions and orientations of the three bodies are computed in a Heliocentric J2000 frame at a given epoch (the *input*) using MATLAB toolkits and SPICE libraries. This is helpful for taking into account the radio signal's travel time, during which the configuration changes. Since the subsequent geometrical problems are better stated in a Vesta-fixed frame, a change of reference frame is performed afterwards. Thus no aberration is taken into account. However, this error is negligible and it does not affect the successful arrival of the signal at the Earth receiving station.

2.2 The point of specular reflection

Under specific hypotheses which underlie the physical model we use for BSR experiments, the main contribution to the received signal derives from a mirror-like reflection, with the angle of incidence equal to the angle of reflection [4]. The most challenging problem in the bistatic geometry is to determine the point P, on the mean surface of the target, which corresponds to specular reflection from the transmitter T to the receiver R (see Fig. 1).

For MEX experiments, Mars was modeled as a sphere and numerical methods were used to find the point of specular reflection P [5]. In the case of Vesta, even for a first approximation a more complex model than a sphere is preferable. Hence, we hereafter propose a mathematical solution to this problem for the case of a target shaped with a more general three-axis ellipsoid.

Let $\vec{n}$ be the normal vector to the ellipsoid at the point P. When vectors $\vec{n}$, $\vec{PT}$ and $\vec{PR}$ lie in the same plane, $\vec{n}$ intercepts a point V along the segment TR. This narrows the research for the point P to the points whose normal intercepts the segment TR. That means we can look for V, whose general expression is:

$$\vec{V} = \vec{T} + \lambda \cdot (\vec{R} - \vec{T}) \tag{1}$$

where $\lambda \in (0, 1)$. Since $\vec{PV}$ is the bisector of the angle $T\hat{P}R$, the *angle bisector theorem* gives:

$$\frac{RV}{PR} - \frac{TV}{PT} = 0 \tag{2}$$

After choosing an initial V', depending on the sign of $\epsilon = \frac{RV'}{PR} - \frac{TV'}{PT}$, an iterative method leads to the sought point. The procedure is based on the subproblem of finding the normal projection of a point on the ellipsoid; many algorithms for this purpose exist and for a spheroid there is a closed solution.

The specular reflection point is not constant. Fig. 1 shows various points P computed by the software within a time window. Continuous pursuit of the point P is interrupted when the angle of incidence reaches $90°$ (*occultation*). The software recognizes this configuration by solving simple geometrical problems of mutual visibility.

3. Summary and Conclusions

Bistatic radar experiments can be used to study Vesta, in addition to the observations already adopted for the Dawn mission. We have described the main features of a new software tool, which can be used to plan such experiments. BSR complexity at Vesta derives from the irregular shape of the asteroid. The ellipsoidal shape assumed for this tool gives more accurate predictions in comparison with the spherical models used in other BSR experiments.

Even though the software has been designed for the Dawn mission at Vesta, the algorithm can be easily adapted for other applications, e.g. for the next target of the Dawn spacecraft, Ceres.

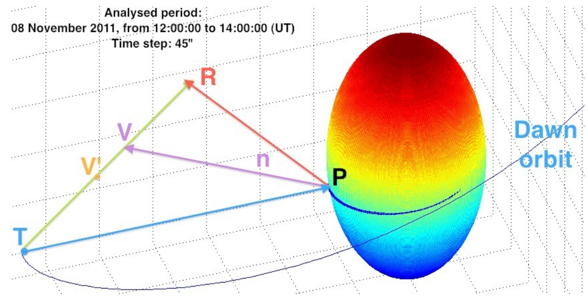

Figure 1: Output *data of the software. INPUT:* time window *and* time step. *OUTPUT:* position of P *and* angle of incidence. *The blue line on the surface of the ellipsoid identifies the set of points P for various instants within the selected time window. The three vectors refer to the first sample time.*

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