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Positioning on Mars by Measurements of Solar Irradiation Decreases from Eclipses

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Abstract

In this work we present an alternative localization method for Mars probes based on the detection of solar irradiation decreases due to Phobos eclipses. This positioning will be useful if positioning using radiometric data is inhibited. We address the inversion of the non-linear, non continuous and multivaluated function modeled to predict eclipses, as well as the establishment of eclipse observation strategies.

1. Introduction

The main purpose of this work is to present an alternative localization method by means of the observation of Phobos eclipses. The methodology is applied to the Mars MetNet mission, initiated and defined by the Finnish Meteorological Institute, whose scope is to deploy semi-hard landing vehicles on the Martian surface mainly focused on the atmospheric sciences [6].

Mars probe landing coordinates are needed to provide useful information for both scientific, for an in situ characterization of observed atmospheric parameters; and mission engineering goals, allowing to analyze the trajectory through the Martian atmosphere during entry–descent, and landing phase; and therefore, allowing to characterize atmospheric vertical profiles.

2. Eclipse Prediction Model

To predict Phobos eclipses contact times for an observer with known position, we have considered Phobos projection onto the Sun disc plane, modeled as an ellipse centered at Phobos center projection. Then, initial and final contact points of any possible eclipse are then determined when the resulting ellipse intersects the Sun disc [1].

The developed model and the involved parameters have been checked with the available observations of Phobos eclipses on Mars by the Mars Orbiter Laser Altimeter and the Mars Exploration Rovers, allowing to choose the values of the parameters which better fit the eclipse observations [1].

3. Observational strategy

For the establishment of an observational strategy for a Mars lander with unknown coordinates, the spatial and temporal patterns of the Phobos penumbral footprint on Mars have been also modeled. Phobos shadow center motion, as well as its size and shape at any given time [5, 6] have been characterized, allowing to determine the coverage and visibility of the Phobos eclipses within a range of latitudes of $\pm 70^{\circ}$ during two eclipse seasons every Martian year. On the average, there is a daily occurrence of 3.2 eclipses every 7.657 hours, covering mean stripes of about 166º.824 around the equator in about 55 minutes each, accelerating as they move away from the subsolar point (see Figure 1).

The 2-D shadow elongates when the subsolar latitude rises, as the shadow travels from one hemisphere to the other within an eclipse season; and also in a single transit, as the shadow moves away from the central meridian of the Sun, yielding a wide pseudo-ellipse at the end of each transit.

This model has been applied to characterize the temporal occurrence of solar eclipses for MetNet and Mars Science Laboratory (MSL) missions.

MetNet precursor mission (MMPM) is aiming to a $\delta\varphi = \pm 5^{\circ}$ latitudinal landing site band around the equator, for which the observational windows have been characterized (see Table 1 for the 2014-2016 Martian year). Results have been also applied to set up a predefined operational strategy at regular time intervals for the eclipse data acquisition by a solar irradiation sensor onboard MetNet [7].

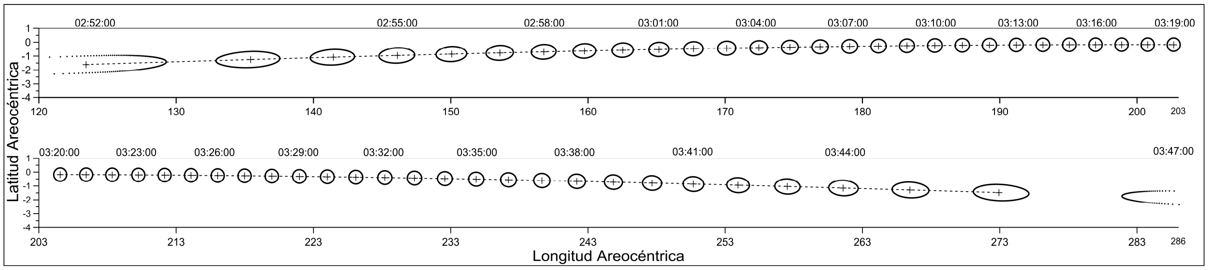

Figure 1: Shadow size and shape every 60 seconds in a transit (22/Sept./2012, 2:51:38–3:47:05), crossing the equator. Dotted line shows the Eastward movement direction of the shadow.

Table 1: Eclipse observational dates for the δφ=±5º latitudinal landing around the equator.

Year	Start	End
2014	02/Ago.(1.8117 h)	24/Aug (18.4587h)
2015	02/Jun (3.7757 h)	03/Jul. (18.8187 h)
2016	25/Jun. (1.6955 h)	17/Jul. (18.3425h)

Besides, the model has been also applied for the Mars Science Laboratory [3]. In this case, a landing ellipse of 25x20 kilometers was known before the launch. To maximize the detections and to improve the precision of the derived times within this landing ellipse, a Monte Carlo simulation has been applied using the eclipse model from an observer with known coordinates for a range of random locations.

The characterized eclipses [3] have already been captured by the Mast Camera onboard the MSL on 13 and 17 September 2012 [4] and on 13, 17, 19 y 20 August 2013 (http://mars.jpl.nasa.gov). This has allowed to prove the methodology reliability for the establishment of an observational strategy

4. Positioning

The problem of determining the coordinates of Mars landers from eclipse data has been addressed by inversion of the non-linear, non-continuous and multivaluated prediction model depicted in section 1.

Two different algorithms have been considered to solve the proposed unconstrained nonlinear least squares problem: the Levenberg-Marquardt method and the block relaxation method [2].

To test their feasibility and efficiency, different simulations have been carried out, under different experimental constraints, trying to locate the MMPM probe: Different initial conditions and locations, different uncertainty values for time precision and different number of observed eclipses and latitude.

The dispersion is kept at 1 kilometer level, for both estimated latitude and longitude, if the precision in time observations is less than 5 seconds, even though this dispersion is sensitive to the number of observed eclipses, rising for higher latitudes when a lower number of eclipses are detected.

As a main conclusion, the numerical results show how, for the latitudinal band of δφ=±5º around the equator, the lander position could be estimated within an ellipse of 20x15 meters if 0.1 second uncertainty in time observations were attainable.

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