Application of Non-coherent Data Types for Deep Space Navigation

Shy am Bhaskaran
Jet Propulsion laboratory
California Institute of Technology
Pasadena, California

1 Introduction

With increasing emphasis on controlling the costs of deep space missions, several options are being examined which decrease the costs of the spacecraft itself, One such option is to fly spat.ccraft in a non-coherent mode, that is, the spacecraft does not carry a transponder and cannot coherently return a Doppler signal. Historically, such one-way data has not been used as the sole data type duc the the inst ability of the onboard oscillator, the use of S-band frequencies, and the correspon ding larger error sources which could not be modelled. However, with the advent of high-speed workstations and more sophisticated modelling ability, the possibility of using one-way data is being re-examined. This paper addresses the navigation performance of various one-way data types for usc in interplanetary missions. Although the primary focus of this study was on using two-station differenced data to cancel some of the error sources inherent in one-way data, single station data was also incorporated in several of the solutions. Comparisons are given between results employing Doppler data formulated as standard differenced-count Doppler (which yields a frequency measurement) as well as accumulated phase (which yields a distance measurement, usually given in terms of cycles). The test case used to compare results against a standard data tracking schedule was a trajectory for the MESUR (Mars Environmental Survey) Pathfinder mission to Mars.

2 Data and Filter

The four data types used in this study were one-way Doppler, one-way differenced Doppler, one-way phase, and one-way differenced phase. All data were at X-baud frequencies.

In this filter model, all dynamical and error effects on the data are modelled aud explicitly solved for, The dynamic. parameters included the spacecraft state (position and velocity), coefficients for solar radiation pressure, random non-gravitational accelerations, and spacecraft maneuvers. Error sources which affect the data include media calibration errors (wet and dry troposphere, day and night ionosphere), and Earth platform calibration errors (station location in cylindrical coordinates, pole location in cartesian x and y coordinates, and Earth rotation).

When one-way data is used, several additional error sources must also be taken into account. For single station data, the largest error source is the frequency drift of the spacecraft oscillator, which was modelled as a drift and bias over snort time spans. This bias and drift are effectively cancelled out when using differenced data. For one-way phase data, parameters arc needed to mode] the phase bias and drift also.

3 Results

A covariance analysis was performed using the data and filter characteristics described above. Several data weights were used, and parametric studies were done to test the sensitivity of the results to various filter parameters. The results were compared to values obtained using standard two-way Doppler and range tracking data. The results indicate that differenced one-way data is very effective in determining the spacecraft position in the cross line-of- sight directions, but very poor in determining the range to the spacecraft. For example, the 1σ dispersions in the radial, transverse, and normal directions are 360.9, 20.3, and 11.6 km, respectively, using differenced phase data, as compared to 3.9, 6.4 and 7.2 km using standard Doppler and range. When differenced data is augmented with single-station one-way data, these values are brought down to 27.1, 9.6, and 11.1 km. 'J'bus, the combined differenced and single station data numbers arc fairly comparable in the cross line-of-sight directions to the standard case, and roughly a order of magnitude larger in determining the range. Similar values are obtained with combinations of one-way Doppler data. The results are somewhat surprising since it has long been assumed that the inherent instability in spacecraft oscillators precludes the.uscofone-way data as the sole data type, but it is shown that proper modelling can remove this error source.

The solutions obtained in this study presents the possibility that using a combination of single-station and differenced one-way data types may be a realistic option for interplanetary missions. Conclusive evidence of this, of course, would depend on the particular mission scenario and its requirements.