Deep Space Orbit Determination with ODTK

1 Introduction

ODTK can be used to perform operational orbit determination and orbit determination studies for deep space missions including spacecraft in orbit about the Moon, about the Sun or in the vicinity of Lagrange points in the Earth-Moon or Sun-Earth systems. There are some limitations to the current capabilities, however, that should be understood in order to use the tool properly.

2 Observation Models

ODTK can process several types of tracking data produced by JPL's deep space network (DSN): two-way sequential range, two- and three-way Doppler, and two- and three-way total count phase. In the context of the DSN, *two-way* indicates observations where the signal is transmitted and received by the same ground station. *Three-way* measurements involve the signal being transmitted from one ground station and being received by a different ground station.

ODTK can also process non DSN range and Doppler measurements for deep space probes using its standard range and Doppler models, though the light time delay in this case is modeled in the geocentric reference frame as opposed to an inertial frame with origin at the solar system barycenter.

Other observation models available with ODTK including GPS, right ascension, declination, azimuth and elevation angles are not valid for use when the satellite of interest is in orbit about the Sun or the Moon. Upgrades to these models can be made for future releases of ODTK if they are required for deep space OD.

3 Gravity

Gravity information for all central bodies of interest is specified in the ODTK scenario object. The geopotential model is specified in the Earth definition section. Gravitational potential models for other central bodes are specified in the CentralBodyList.

ODTK provides a gravity process noise model which is used to account for dynamical uncertainty related to uncertainty in the gravitational potential of the primary body associated with each satellite. The inputs for the gravity process noise model are constructed from the variances associated with the potential function coefficients and may be included in the AGI gravity file (.grv). The methods for constructing the process noise inputs can be provided in the form of technical whitepapers, but the capability to generate the process noise inputs from the gravity potential error covariance is not currently part of ODTK. For Earth gravity fields, a heritage model generated for the JGM2 gravity field can be used if model specific information is not included in the .grv file. For other central bodies, the process noise inputs must be supplied in the gravity files for gravity process noise to be computed and applied.

It is important to note that despite the fact that full gravity fields may be specified for the Earth, Sun and Moon, the gravitational parameters associated with these fields are not the values used when the body is included as a third body perturbation. The values of the gravitational parameter used in the computation of third body perturbation are taken from .cb files with the exception of the Sun and the Moon where the values are currently hard-coded. The restriction with respect to the Sun and Moon is expected to be removed in a future version of the software.

4 The Central Body of a Satellite

When a satellite is initially created, the user has the option to set the central body for the satellite as part of the OrbitState settings. This selection indicates the origin of the reference frame for the initial conditions and the central body which will be considered as the primary body for trajectory integration. A complete gravitational potential is used for the primary body only, other bodies may be considered as point masses. Changing the central body selection in the OrbitState does not preserve the absolute position and velocity of the satellite. A method for changing the central body selection while preserving the absolute position and velocity of the satellite is described below.

4.1 Changing the central body of a satellite

Sometimes the primary body for a satellite will change throughout its mission. A typical example is a mission which starts in an Earth centered parking orbit, then performs a lunar swingby to initiate a heliocentric transfer to another body. In these cases it will be necessary to change the central body of the satellite for the purpose of orbit determination.

It is not currently possible to change the central body of the satellite and use a filter restart record to continue estimation relative to the new origin. Instead, ODTK provides the ChangeCentralBodyTool, an HTML panel which can be launched from the Utilities tab on the LaunchPad. This tool allows you to change the central body of the satellite in a manner that also converts the OrbitState to be relative to the new origin and reference frame. A typical workflow would be to use the InitialStateTool to set the OrbitState from an ephemeris file generated by either the Filter or the Smoother. The filter must then be run in initial mode once to establish a restart record relative to the new central body. It is advisable to run two filters, in different scenarios, in parallel to ensure a smooth transition. This provides the following benefits:

- The orbit determination relative to the new central body can be checked against the current solution for consistency prior to switching operationally

- The separate filters will create separate restart record histories to allow for more recovery paths in case of a contingency
- The separate filters will create separate inputs for the smoother allowing for consistency checks on the smoothed solutions as well

The user should be aware that force modeling updates will likely be required when changing the central body of the satellite. The ChangeCentralBodyTool will automatically change the third body perturbations list when the primary body is changed and will also reduce the degree and order of the primary gravity field if necessary based on the size of the field available for the new central body.

4.2 Smoothing

It is not currently possible to smooth across multiple .rough files where the central body associated with a satellite changes between rough files.

4.3 Simulation

Tracking data may be simulated (see section on measurement models above) with satellites specified relative to any central body. Estimation may be performed with the satellite relative to the same central body used for simulation or the central body may be changed prior to estimation.

4.4 State Differencing

The state differencing function (StateDifferenceTool) may be used to difference run files where the same satellite is specified relative to different central bodies. This capability is useful when comparing solutions of an Earth based run with that of Moon based run for example. The radial, in-track and cross-track directions for the differences will be expressed using directions defined by the reference satellite in the difference operation.