Deep-space Orbit Determination with the ODTK Application

1 Introduction

You can use the ODTK application to perform operational orbit determination and orbit determination studies for deep-space missions, including spacecraft in orbit about the Moon, about the Sun, about another planet or asteroid or in the vicinity of Lagrange points in the Earth-Moon or Sun-Earth systems. There are some nuances to these capabilities, however, that you should be aware of so you can use the tool properly.

2 Observation models

ODTK software can process numerous data types of tracking data produced by JPL's deep-space network (DSN): two- and three-way sequential range, two- and three-way pseudo-noise range, one- two- and three-way Doppler, one- two- and three-way total count phase (TCP) and delta differenced one-way range (DeltaDOR). 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 received by a different ground station. One-way measurements involve signals originated by a spacecraft and received at a ground station.

ODTK software 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 the ODTK application including GNSS, right ascension, and declination are also available for use in deep space orbit determination scenarios. Additionally, tracking stations can be located on the Earth or on other planetary bodies.

3 Gravity

Historically, gravity information for all central bodies of interest has been 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. When using the ODTK Component Browser for the specification of force modeling through a selected Propagator, gravitational potential selection is made as part of the definition of a propagator.

ODTK software provides a gravity process noise model that 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 formal 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 found in the form of technical whitepapers, but ODTK software cannot natively generate the process noise inputs from the gravity potential error covariance. Instead, this is currently performed as an offline process. For Earth gravity fields, you can use a heritage model generated for the JGM2 gravity field if you do not include model-specific information in the GRV file. For other central bodies, you must supply the process noise inputs 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 any central body, the gravitational parameters associated with these fields are not necessarily 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 can be selected when configuring the propagator settings.

4 The central body of a satellite

When you initially create a satellite, you have 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 that will be considered as the primary body for trajectory integration if your satellite is not configured to use a Propagator component from the Component Browser. When using a propagator from the Component Browser, the selection of the primary gravitational body in the propagator definition will serve to dictate the center of the inertial frame used for propagation. If the propagator central body is different than the central body selection in the satellite initial conditions, the satellite initial conditions will be transformed to the propagation frame at the start of processing. Note that changing the central body selection in the OrbitState settings of the satellite 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 that starts in an Earth-centered parking orbit and then performs a lunar swing-by to initiate a heliocentric transfer to another body. In these cases, you will want to change the central body of the satellite at certain times within the mission for the purpose of orbit determination.

You cannot change the central body of the satellite and use a filter restart record to continue estimation relative to the new origin. Instead, the ODTK application provides the **Change CentralBody Tool**, an HTML panel that you can access by going to the **Utilities** menu, selecting **All Utilities**, and opening the tool in the **Utility Manager**. This tool enables 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 Save a copy of your scenario to retain the ability to estimate the satellite trajectory around the current primary body. Next, use the ChangeCentralBody utility to update your satellite and the Filter restart record to reference the new central body. You can then continue processing data without interruption in the new reference frame. It is common practice to run two filters, in different scenarios, in parallel to ensure a smooth transition. This provides the following benefits:

- You can check the orbit determination relative to the new central body 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.

You should be aware that force modeling updates will be required when changing the central body of the satellite. The **Change Central Body Tool** provides for the specification of a new Propagator from the Component Browser to facilitate the change. The main changes in force modeling should be in terms of the gravitational bodies. You will want to retain the same formulation and settings for solar pressure.

4.2 Smoothing

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

4.3 Simulation

The Simulator object has an option to EnableDeepSpaceMode in the ProcessControl settings. When set to *true*, this option will change the manner in which the Simulator generates observations to be more efficient in deep space scenarios. In the normal, or near-space mode, observations are generated inside the time update loop that moves the estimation state across the simulation interval. In deep-space mode, the computation of the state history and generation of measurements are separated. This allows for the interpolation of the state history during measurement generation and avoids the need to propagate the satellite state across significant time intervals to account for the effect of light time delay.

You can simulate tracking data — see the section on measurement models above — with satellites specified relative to any central body. You can perform estimation with the satellite relative to the same central body used for simulation or you can change the central body prior to estimation.

4.4 Filtering

The Filter object has an option to EnableDeepSpaceMode in the ProcessControl settings. When set to *true*, this option will change the manner in which the Filter processes observations to be more efficient in deep space scenarios. In the normal, or near-space mode, observations are processed after the Filter time update moves the estimation state to the time tag on the measurement. In deep-space mode, certain types of measurements publish an additional approximate time when the measurement signal passed through the spacecraft. In such cases, the Filter is able to move the estimation state to this alternative time for the purpose of processing the measurement and avoid the need to propagate the satellite state across significant time intervals to account for the effect of light time delay.

4.5 State differencing

You can use the state differencing function (**State Difference Tool**) 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. It is important to note, however, that 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 and will, therefore, have different meaning depending on which central body the reference satellite is defined relative to.