Reducing the Lunisolar Numerical Ephemeris for On-board Applications

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Keyword: Lunisolar ephemeris; On-board application; Ephemeris reduction

Ephemerides of natural celestial bodies are needed in space missions, especially in computing the gravitations from the perturbing bodies, among which the Moon and the Sun are of great importance.

To obtain the lunisolar positions, one can use the conventional analytical formulas derived from Celestial Mechanics, which generally has a concise form but is relatively poor in accuracy. The accuracy problem is especially significant for the Moon, which has a strong perturbation on the medium/high altitude Earth orbit but has an inaccurate analytical ephemeris due to the strong solar gravitation on its own orbit. Alternatively, numerical ephemeris, such as JPL DE series or the INPOP series, offers highly accurate results. However, these products are always exhaustive for all the major bodies in the Solar System and are ready to be used in the "as is" form. The excess data increases the size of the ephemerides by several times, and limits its portability for on-board application even sometimes for ground applications.

The work in this paper is set in the background of orbit prediction (OP) on board the GEO satellite. Assuming the satellite orbit is updated every 4 hours, on-board OP is expected to be responsible during the period. The model parameters are designed to be updated via uplink from ground stations every 180 days, suggesting that if the ephemerides are to be simplified, each set of simplified ephemeris parameters should satisfy the accuracy within the period.

Since the on-board OP requires only the Cartesian coordinates to compute the gravitational perturbations, we focus on the simplification of the lunisolar position vectors. The lunisolar ephemerides are simplified in two ways, based on the JPL Development Series (DE406 is used as an example).

One method involves spectrum analysis on the lunisolar orbits, which are generated with a reasonable time interval. A full ephemeris spanning approximately 200 years is first analyzed using the conventional Fourier transformation (e.g., FFT). In case the signal-to-noise ratio of certain frequencies are not large enough when the original time series are analyzed, the residual series are analyzed for smaller signals and the procedures may be repeated several times. The frequencies are then used to fit the 180-day intervals as requested. The frequencies, together with the associated amplitudes/phases, represent the new parameterization of the lunisolar ephemerides.

The second method is more straightforward, in terms that the raw ephemeris files are directly processed. Since only the lunisolar positions are significant in the on-board OP, it is possible that we remove the excess constants and celestial bodies in the ephemeris files and only keep the lunisolar parameters. The lunisolar ephemeris can be further reduced if certain reasonably lower accuracy is allowed and the Chebyshev polynomial is applied to a larger time interval than current DE configuration.

With either method, we can quantify the size of the reduced ephemeris (number of parameters) with respect to different accuracy requirements. The two methods are also to be compared with each other and a preferable option can be found for the on-board implementation. It is noteworthy that for other on-board application, such as in deep space missions, the ephemerides for other bodies like Mars or Venus can be likewise reduced.