IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation & Control (1) (7)

Author: Mr. Takahiro Ito
Japan Aerospace Exploration Agency (JAXA), Japan, ito.takahiro@jaxa.jp

Prof. Shin-ichiro Sakai
JAXA-ISAS, Japan, sakai@isas.jaxa.jp

THROTTLED EXPLICIT GUIDANCE FOR LUNAR AND PLANETARY PINPOINT LANDING

Abstract

The paradigm shift has been prompted in the quality of lunar and planetary landing accuracy. For pinpoint landings on the order of 100 meters from the target, fuel-optimal large-divert (FOLD) maneuverability is indispensable for the onboard guidance. When the FOLD problem is simplified with constant gravity, negligible atmosphere, and bounded thrust magnitude, the solution is known that the optimal thrust magnitude has the maximum-minimum-maximum structure with at most twice switches and the thrust direction follows the bilinear tangent steering law.

Powered explicit guidance (PEG) was originally developed for Shuttle's onboard guidance. Although it was originally designed for its exoatmospheric ascent flight, there are many common principles among the descent and ascent guidance. Different from the Apollo descent guidance, PEG follows the optimal control theory and repeats the predictor-corrector iterations, where the final states are predicted analytically and their errors are corrected to meet the final conditions. However, when PEG is applied to the FOLD problem, one improvement to be made is the computation of the optimal thrust switching. As PEG assumes the thrust profile as a known function of time, it is impossible to realize large-divert maneuvers with its maximum thrust range capability, which would limit the maneuverability and fuel-optimality of a lander.

The descent guidance based on convex optimization is also the potential onboard guidance for pinpoint landings. They generate a trajectory by solving a second-order cone program, where the states and commands are discretized. Its advantage is that it can find the fuel-optimal solution (including thrust switching) with various constraints such as thrust pointing and glide slope, whereas they typically have difficulty in the real-time computation. In contrast, the advantage of the predictor-corrector based algorithm is that its algorithm is simpler, a smaller number of control variables is output, and it would require less computation time. Therefore, these two different algorithms potentially complement with each other. Particularly for the computation time, the predictor-corrector based algorithm would be suitable for the missions that take priority on the faster computation rather than the greater flexibility of the constraint treatment for the onboard guidance.

With these backgrounds, the authors developed Throttled Explicit Guidance (TEG) for pinpoint landings, which is capable of fast, explicit, and simultaneous search of the optimal thrust direction, thrust magnitude switching, and time-of-flight in the predictor-corrector iterations. This paper demonstrates the performance of the TEG algorithm by a series of practical simulations for pinpoint landings.