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ON-ORBIT OPERATION RESULTS OF THE POWERED DESCENT GUIDANCE ALGORITHM FOR PINPOINT LUNAR LANDING

Abstract

This paper discusses the on-orbit operation results of the powered descent guidance algorithm that played a key role in the navigation, guidance, and control of the SLIM (Smart Lander for investigating Moon) mission that achieved a pinpoint lunar landing in January 2024. The SLIM mission successfully demonstrated pinpoint lunar landing technology and the landing accuracy was confirmed to be within 100 meters. The technology required for pinpoint lunar landing consists of a variety of elements including a vision-based navigation system that accurately detects the relative position of the spacecraft to the lunar surface, a propulsion system that operates stably, a landing and descent reference trajectory that is in harmony with the system design, mature spacecraft navigation, guidance, and control technology, and precise guidance algorithms to accurately guide the spacecraft to its target state.

The SLIM landing and descent sequence consists of two phases: the powered descent phase to reduce the horizontal velocity, and the vertical descent phase for reduction of the remaining vertical velocity after the powered descent. Dedicated guidance algorithms are applied for powered descent and vertical descent, respectively, and both guidance algorithms have advanced mathematical methods for high-precision landing and backup options for a variety of situations.

This paper focuses on the powered descent guidance algorithm. The powered descent phase consists of three boost sections and two coasting sections. The coasting sections are introduced to change the attitude of the spacecraft to adjust the direction of body-fixed navigation camera. Image acquisition for vision-based navigation, followed by guidance calculation for the next boost section, is performed prior to the powered descent and during the coasting section. The guidance calculation is performed once

just before each boost section. In the boost section, the spacecraft's translational control law follows the trajectory generated by the guidance algorithm.

The powered descent guidance algorithm uses an explicit guidance method that sequentially calculates the optimal trajectory and necessary controls during flight. Guidance algorithms are required to achieve highly accurate guidance while adapting the control acceleration to the actual thrust acceleration of the spacecraft. To achieve these goals, unique mechanisms are introduced: trajectory generation based on polynomials with respect to dimensionless time, and boost start time correction based on navigation and machine learning. These mechanisms worked properly and achieved guidance accuracy within 0.2%, contributing to pinpoint lunar landing. This paper presents details of these mechanisms and their evaluation based on telemetry during landing.