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DATA-DRIVEN GUIDANCE FOR ASTEROID LANDING BASED ON REAL-TIME DYNAMIC MODE DECOMPOSITION

Abstract

In the microgravity environment in the vicinity of asteroid, there are strong uncertainties such as control error of the spacecraft and surface roughness of asteroids, and non-uniform gravitational fields due to their shapes of asteroids which should be taken into account for the operations of descent and landing. Mission design to unvisited small bodies is challenging because limited information of the target is available in advance. In general, in order to accurately determine the shape and gravitational field of asteroids, a long in situ characterization campaign which largely rely on Earth ground segment data processing is carried out. In addition, due to the long Earth-to-spacecraft distance, the round-trip propagation time from the ground is extremely long relative to the dynamics time constant (order of seconds) of an operation such as a touchdown on asteroids. Furthermore, guidance systems for asteroid landing would often be a complex system with multiple sensors and actuators.

In this paper, we propose a new guidance and control method based on dynamic mode decomposition (DMD), which is applicable to the dynamical environment near asteroids with strong uncertainties. DMD is one of the powerful data-driven technique to analyze time-series data which was originally developed in the field of fluid dynamics, and has been applied to various fields to extract a simple structure from a complicated dynamical behavior. In this study, we apply DMD for the so-called delayed embedding data, which is used to recover the original high-dimensional dynamical system from low-dimensional observations when the dimension of the state of the dynamical system is small.

Specifically, time-series data obtained from the onboard sensors is used as observables to construct delayed embedding. Then, DMD is applied to compute approximation of nonlinear dynamics as a linear model. In non-uniform gravitational fields, the linear model obtained from the observables works only in a local region, resulting in inefficient control. Therefore, we derive the online DMD that can recursively improve the accuracy of the predictive model by updating the linear model with in-situ estimates reflecting the non-uniform gravity field. Then, we apply a data-driven landing guidance control law based on the obtained accurate linear dynamics model in the vicinity of asteroids.