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STUDY ON 1D-LIDAR-BASED TERRAIN-REFERENCED NAVIGATION FOR MARS EDL LANDER.

Abstract

This study focuses on estimating the state variables of a Mars lander during entry, descent, and landing (EDL) by integrating IMU-based inertial navigation with 1D-LiDAR-based terrain-referenced navigation (TRN). Unlike imaging LiDAR, 1D-LiDAR can accurately measure long profiles and actively collect terrain data.

The Mars landing process using an EDL lander can be divided into two main phases: atmospheric entry and powered descent. The atmospheric entry phase means from outside Mars' atmosphere to inside. Since the lander must safely enter while overcoming atmospheric effects, precise navigation is critical. This study develops an extended Kalman filter (EKF) based on a refined dynamic model that accounts for aerodynamic effects and lift-to-drag ratios. Additionally, it analyzes the computed navigation solution by considering sensor limitations in the Martian environment.

The powered descent phase follows atmospheric entry and utilizes thrusters for landing. Since GPS is unavailable on Mars, this study integrates an inertial navigation system (INS) with TRN to determine the navigation solution. Assuming prior knowledge of Martian terrain data, an EKF-based navigation system incorporating 1D-LiDAR-based TRN is designed.

To validate the designed navigation system, numerical simulations of a Mars EDL lander are conducted by comparing three types of navigation filters. EKF1 obtains accelerometer measurements and TRN data using a loosely coupled sensor model. EKF2 implements IMU mechanization, where accelerometer measurements are used in the system model, while TRN measurements are obtained through a loosely coupled approach in the sensor model. Finally, UKF follows the same IMU mechanization approach as EKF2 but utilizes a sigma-point-based estimation method as a sampling-based filter.

The simulation consists of four scenarios. The first scenario considers the atmospheric entry phase and assumes that a heat shield is attached to which 1D-LiDAR can operate normally. This scenario aims to validate whether the proposed navigation system is effective. The remaining scenarios focus on the powered descent phase, where the heat shield is removed, and TRN is operational within the practical altitude range of 5–30 km.

This study proposes an INS/1D-LiDAR-based loosely coupled navigation system that enables rapid state estimation even with large initial position errors during the Mars EDL landing process. Various simulations are conducted to evaluate its effectiveness. By improving state estimation accuracy, the proposed

navigation system is expected to reduce landing errors and minimize unnecessary energy consumption by the rover after landing.