National Aeronautics and Space Administration

LiDAR-Inertial Based Navigation and Mapping for Precision Landing

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Program: FY22 R&TD Topics
Strategic Focus Area: Precision Landing

Objective

Demonstrate and mature a 3D Light Detection and Ranging (LiDAR) based, illumination-insensitive navigation and mapping algorithm that ensures safe and precise landing on planetary bodies, e.g., Europa, Enceladus, Mars, the Moon, and small bodies.

Background

New challenges await future JPL lander missions to Europa, Enceladus, comets, asteroids, or permanently shadowed regions of the Moon:

- Limited topographic information about the surface will be available prior to descent; hazards will need to be mapped autonomously; sites of the greatest scientific interest will be near extreme terrain, requiring precision landing; and landing when illumination conditions are similar to those during initial surface mapping, which was a requirement for the camera-based Lander Vision System (LVS) used on Mars 2020, may be impractical.

3D LiDAR provides ranging over an entire field of points, which can be used for both localization and mapping. Together with an inertial measurement unit (IMU), LiDAR can be used to replace or augment a traditional landing sensor suite, and enable safe and precise landing in the face of the aforementioned challenges.

Approach and Results

Estimate the maximum a posteriori trajectory (pose, velocity, and IMU biases at the start of each LiDAR scan) using incremental smoothing.

Make use of various sensing methodologies:

- *Inertial odometry*, which pre-integrates several IMU measurements to constrain temporally adjacent lander states;
- *LiDAR-odometry*, which estimates motion by matching features in temporally adjacent range and intensity images; and
- *Map relative localization* (MRL), which localizes the lander by matching measured LiDAR scans to existing digital elevation models (DEMs)

Use the estimated trajectory to re-project LiDAR range measurements into the existing DEM, refining the map to higher resolutions suitable for onboard safe landing site selection.

Results from FY22 include the application of scanning LiDAR-inertial odometry to simulated Europa Lander and real-world handheld LiDAR datasets. Example feature tracking over LiDAR range and intensity images is shown in Figure 1. Resultant position estimation from scan-to-scan matching is shown in Figure 2.

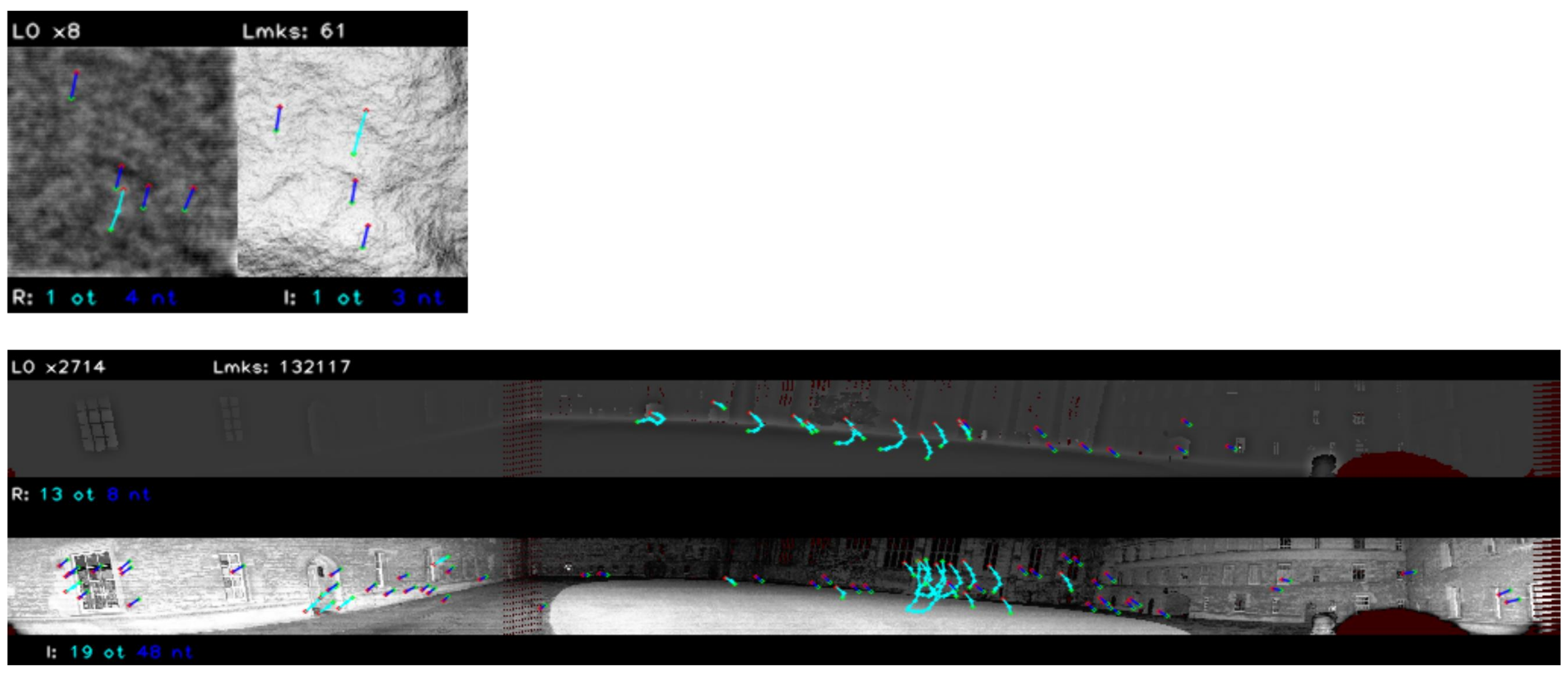

Figure 1: Example Europa Lander (top) and Oxford Newer College (bottom) dataset high-pass filtered range and laser return intensity images with tracked feature trails.

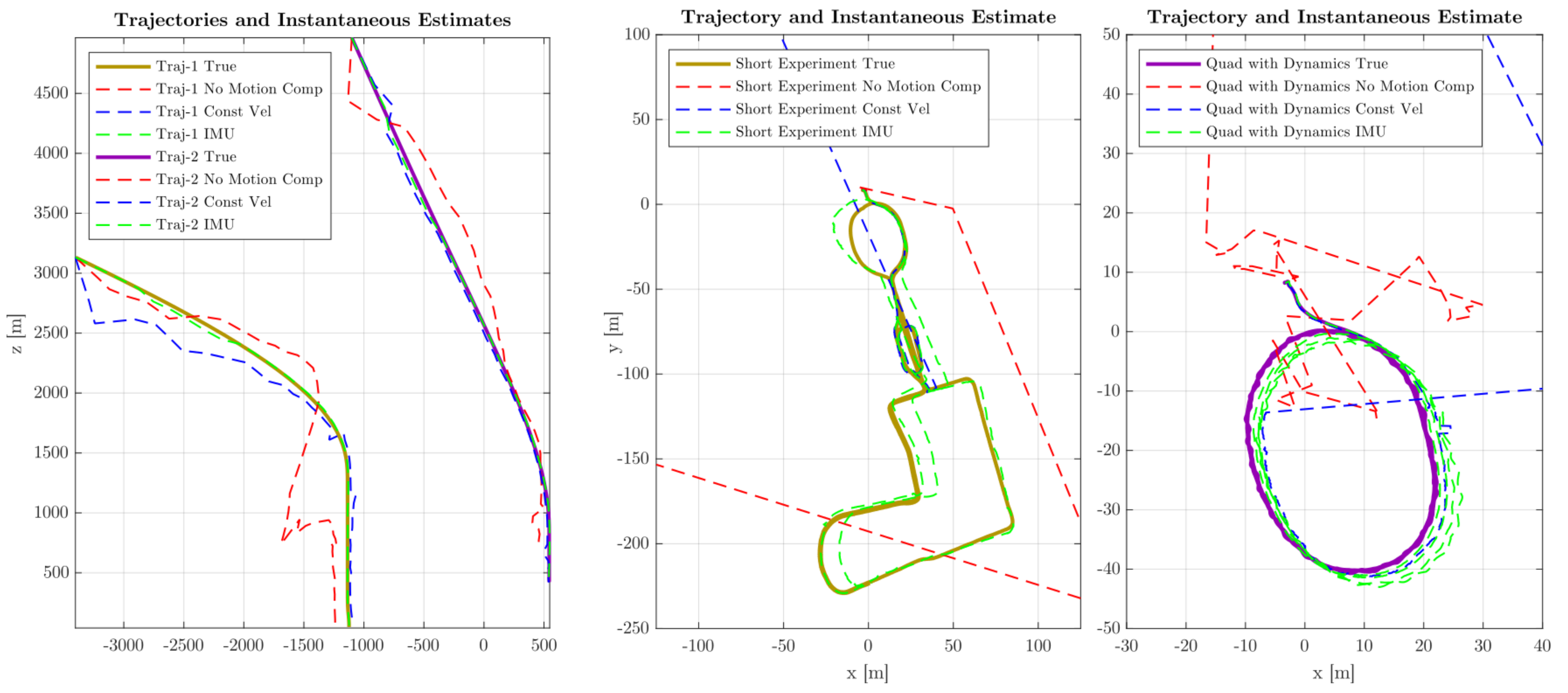

Figure 2: Example Europa Lander (left) and Oxford Newer College (middle and right) dataset LiDAR-inertial odometry position estimation using our IMU-based motion compensation (green) vs other techniques.

Significance/Benefits to JPL and NASA

For missions to destinations other than the Moon and Mars, orbital topographic information is insufficient for safe landing, and scanning LiDARs will likely be included for hazard detection and avoidance. The software from this R&TD vastly expands the utility of carrying such a LiDAR, enabling not just hazard mapping at a single altitude, but also localization, velocimetry, and continuous hazard mapping at a range of altitudes. For missions to partially or fully shaded destinations, or any missions wishing to avoid restrictions on the time of day of the landing, our LiDAR-based navigation offers an illumination-insensitive replacement to the current state-of-the art visual terrain relative navigation.

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Publications:

1. T. P. Setterfield et al., “LiDAR-Inertial Based Navigation and Mapping for Precision Landing,” IEEE Aero Conf, Big Sky, MT, 2021.
2. T. P. Setterfield et al., “Real-World Testing of LiDAR-Inertial Based Navigation and Mapping for Precision Landing,” IEEE Aero Conf, Big Sky, MT, 2022.
3. C. Marcus, T. P. Setterfield, R. A. Hewitt, and P.-T. Chen, “Landing Site Selection with a Variable-Resolution SLAM-Generated Map,” in *IEEE Aero Conf, Big Sky, MT, 2022.*
4. T. P. Setterfield, R. A. Hewitt, A. Teran Espinoza, and P.-T. Chen, “Feature-Based Scanning Lidar-Inertial Odometry using Factor Graph Optimization”, pending submission in IEEE Robotics and Automation Letters, 2022.

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