National Aeronautics and Space Administration

Hardware-in-the-Loop Testbeds for Robust Landing Navigation Systems

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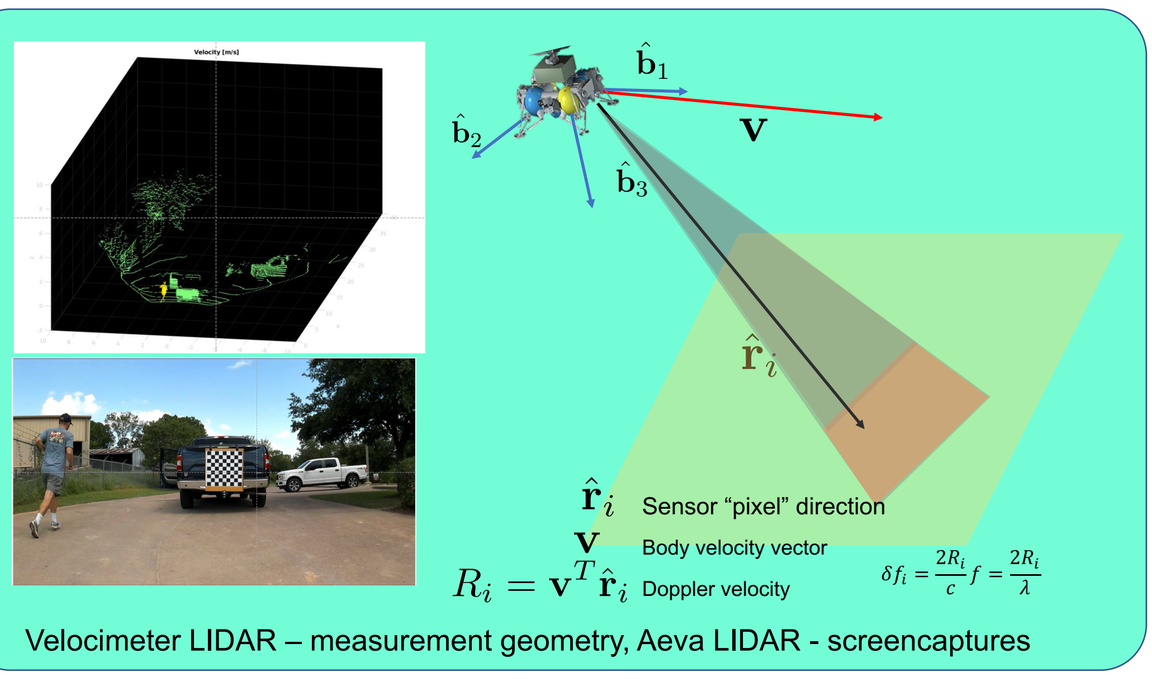
Program: FY22 SURP
Strategic Focus Area: Autonomous GNC, planning, scheduling, and execution

Objectives

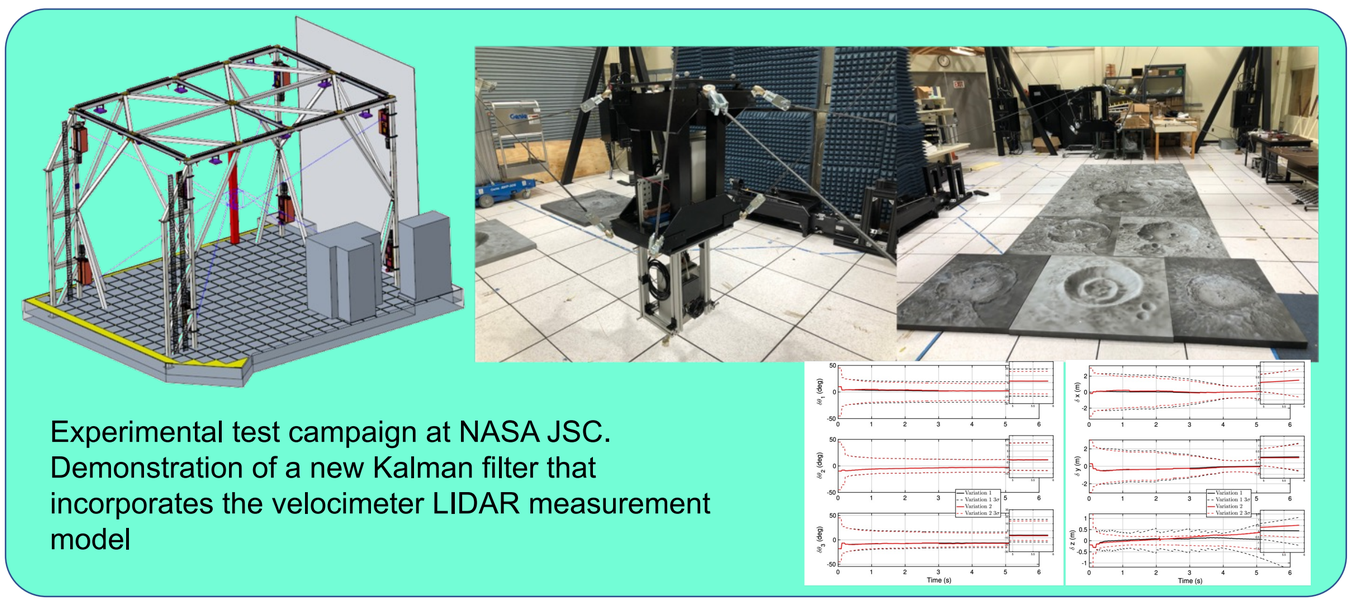
The research objective of this work was to assess the utility of a frequency modulated continuous wave (FMCW) LIDAR technology for safe entry, descent and landing operations of space vehicles, thereby advancing planetary exploration of the next generation.

A secondary objective of the research is aimed at developing hardware-in-the-loop testbeds catered to address JPL mission needs to facilitate sensor modality evaluations for effective guidance and control of vehicles during entry, descent and landing. Hazardous and poorly-mapped environments demand we leverage recent technological advances in sensor systems and integrate them for improved navigation.

This project developed analytical tools to such as a functional model of velocimeter sensors so that better relative navigation algorithms can be developed using the measurements. Experiments carried out at the Texas A&M's Land, Air and Space Robotics (LASR) laboratory, NASA Johnson Space Center (JSC)'s STAR robot and JPL's celesterium, the velocimeter LIDAR functional model, and the relative navigation algorithms built on the model will be tested. Evaluation of the velocimeter LIDAR being aggressively sought after by the autonomous vehicle industry is a unique opportunity afforded by JPL as a part of this SURP study.



Velocimeter LIDAR – measurement geometry, Aeva LIDAR - screencaptures



Experimental test campaign at NASA JSC. Demonstration of a new Kalman filter that incorporates the velocimeter LIDAR measurement model

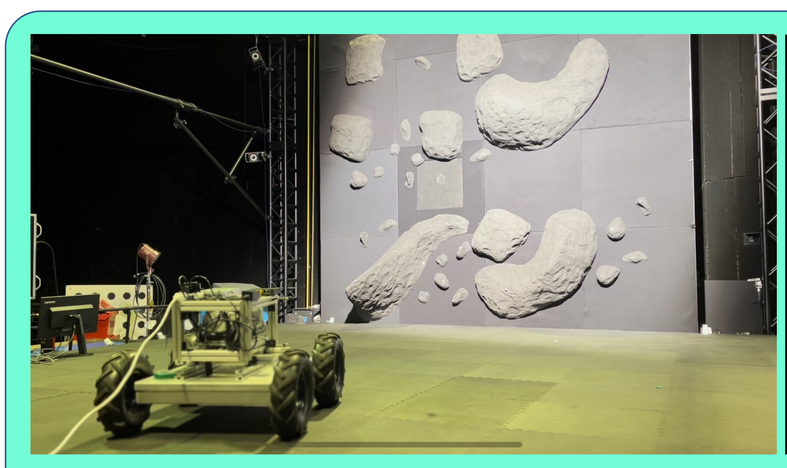
Background

Robust safe landing on hazardous and poorly mapped remote planetary environments requires effective fusion of information from a suite of complementary sensors for terrain-relative navigation and hazard detection and avoidance. The use of Frequency Modulated Continuous Wave (FMCW) LIDAR technology developed mostly for self-driviing automobiles is a promising approach to improve robustness and safety in entry, descent and landing operations.

The use of velocimeter LIDAR in guidance and control of reentry vehicles, and its evaluation in hardware in the loop testing of reentry guidance and control is the state of the art in the world and quite innovative. Hardware in the loop testbeds play a critical role in verification and validation of improved landing systems. This project aims at establishing such a testbed, while evaluating innovative sensing modalities such as the novel velocimeter LIDAR sensor for their utility in entry, descent and landing operations

Approach and Results

1) Robust sensor fusion approaches will be researched to provide terrain relative navigation by exploiting recent advances in computational vision, inertial sensors, and embedded computational frameworks. Novel formulations of the relative state estimation approaches that use all the sensors were derived and implemented.
2) Information gain obtained by using specific sensor selections was compared and it was concluded that velocimeter LIDAR does provide useful ancillary information useful for entry, descent and landing operations. A functional model of the LIDAR was developed for this purpose.
3) Representative terrain models developed at LASR with feedback from JPL Europan scientists were used to evaluate a functional model of the LIDAR system developed in the project. The model was validated using emulation and testing facilities at NASA-JSC and NASA/JPL.



Velocimeter LIDAR mapping experiments at JPL's Celesterium – functional model validation

Significance of Results - Benefits to NASA/JPL

The research results from the SURP project work fundamentally advances System Level Autonomy by furthering approaches for Autonomous GNC, planning, scheduling and execution. It also favorably impacts next generation Entry, Descent, and Landing Systems to achieve robust precision landing. The team has concluded that using velocimeter LIDAR in EDL navigation is quite useful and the use of representative terrain models and emulation testbeds for challenging unstructured environments aids in technology advancement at modest to low costs (as compared to expensive helicopter testing). It is anticipated that a quatification of the value of information provided by the velocimeter LIDAR in entry, descent and landing operations is invaluable in realizing an optimal navigation sensor suite. The research results generated by this SURP project are a significant step toward building understanding and tools that will have an important impact on the accuracy, efficiency and quality of science for of many future missions.

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Publications:

[A] Adams, D. W., Majji, M., "Velocimeter LIDAR Relative Pose Estimation for Autonomous Rendezvous, Proximity Operations, and Docking Applications," presented at the 2022 Rocky Mountain AAS Guidance, Navigation and Control (GNC) Conference and Exhibit, Breckenridge, CO., Feb 3-9, 2022.
[B] Adams, D.W., Peck, C. H., and Majji, M., "Velocitmeter LIDAR-Based Multiplicative Extended Kalman Filter for Terrain Relative Navigation," presented at AIAA SciTech Conference, San Diego, CA, Jan 3-7, 2022.
[C] Adams, D.W., Majji, M., Stevens, S. U., Kulkarni, T., Katake, A., San Martin, A., and Skulsky, E., "Velocimeter LIDAR-Based Bulk Velocity Estimation for Terrain Relative Navigation Applications," presented at AIAA SciTech Forum, San Diego, CA, Jan 3-7, 2022.
[D] Adams, D. W., "Velocimeter LIDAR Information Fusion for Guidance, Navigation and Control of Aerospace Vehicles," PhD Disseration, Texas A&M University, College Station, TX, August, 2022.

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