National Aeronautics and Space Administration

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

Principal Investigator: Sarah Stevens (313); Co-Investigators: Tejas Kulkarni (313), Alejandro San Martin (343), Eli Skulsky (343), Anup Katake (343), Nikolas Trawny (343), Manoranjan Majji (Texas A&M University)

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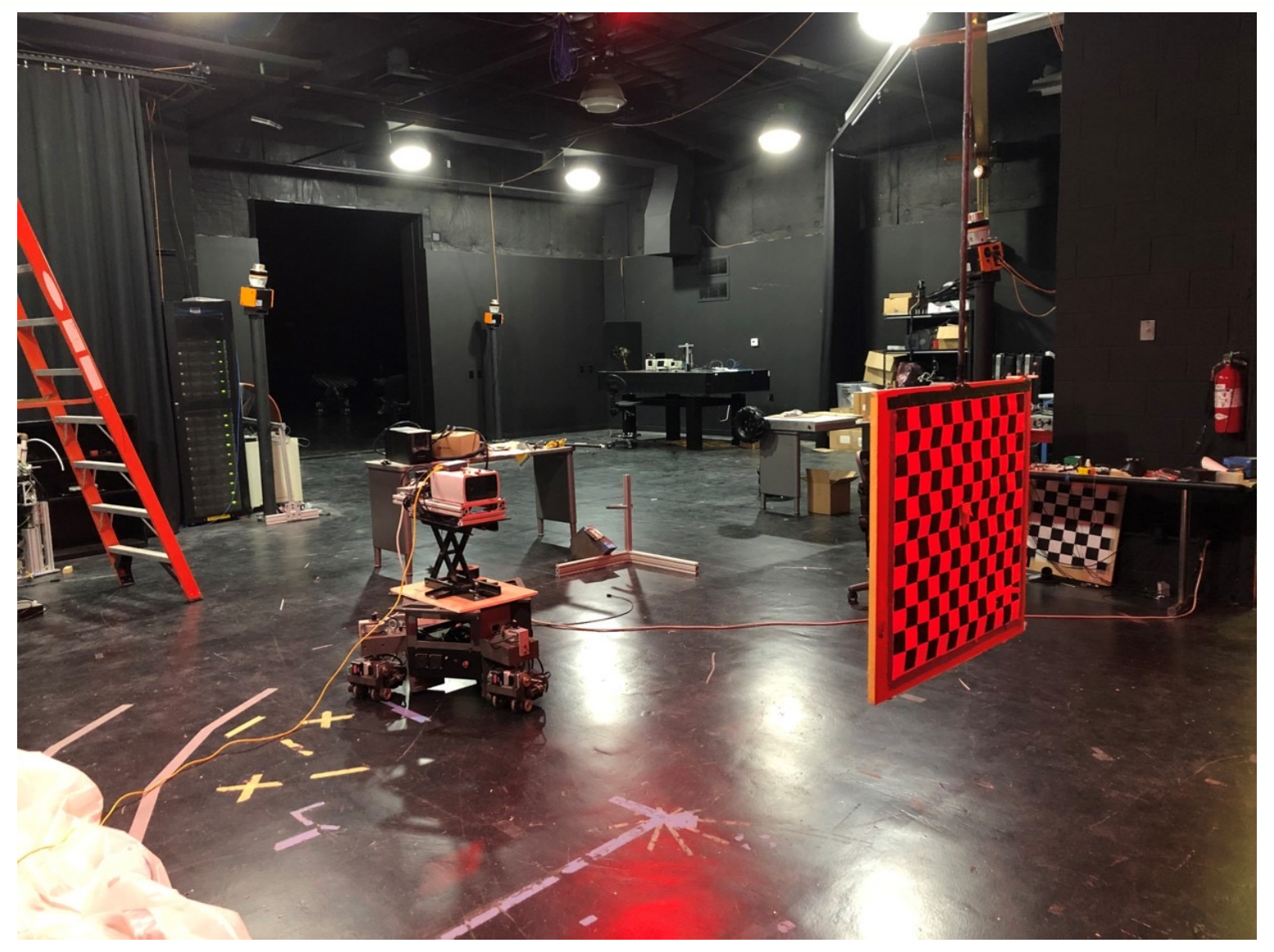

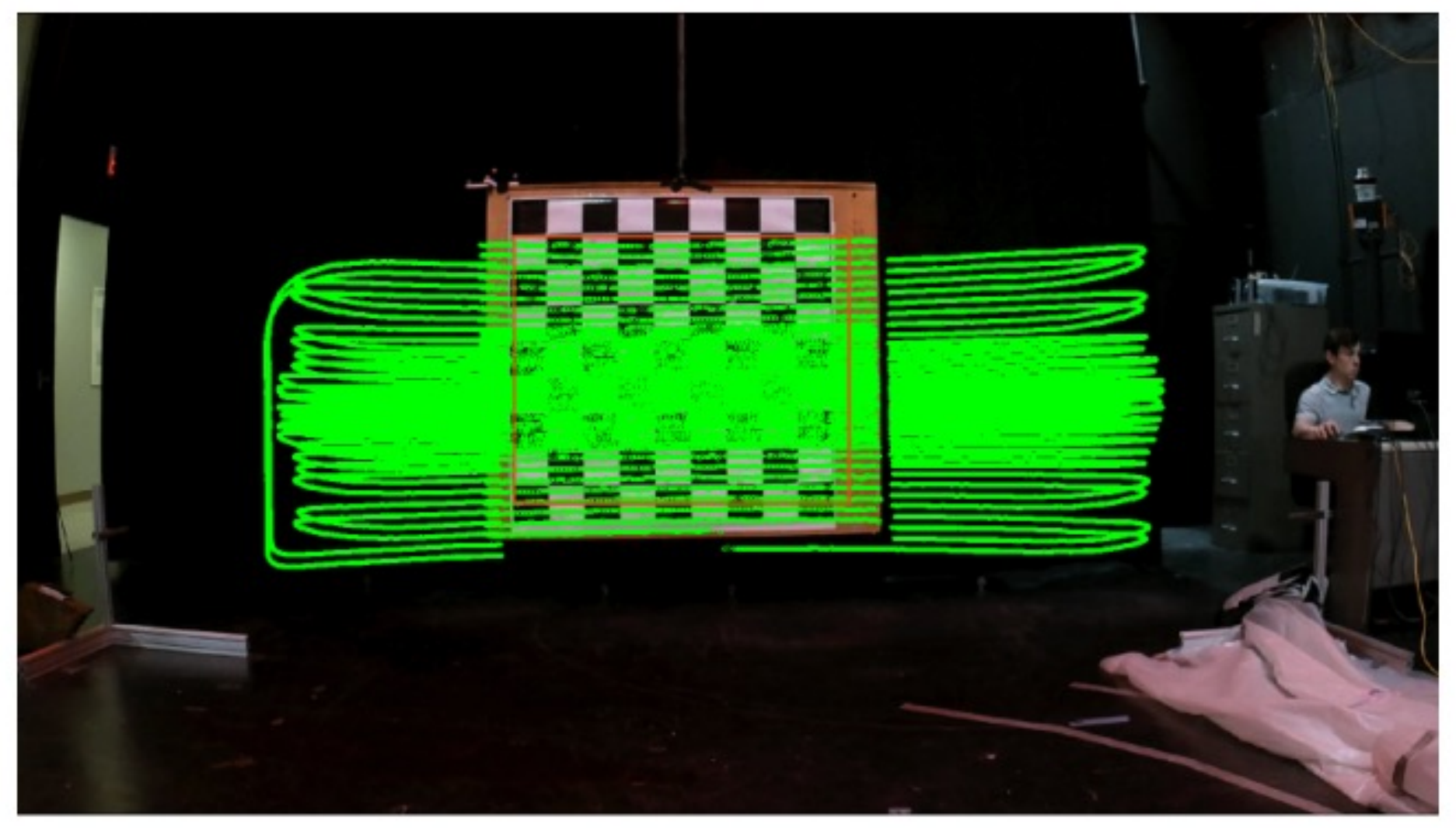

Objectives

The completed research addresses two technical objectives. The first objective is to characterize the noise, imaging characteristics, and behavior of an Aeva A2 velocimeter LIDAR prototype. Precise noise characteristics and calibration parameters are extremely important for accurate and statistically consistent navigation. The second objective is to begin the development of a LIDAR testbed to test the capabilities of a LIDAR system to be used for both Terrain Relative Navigation (TRN) and Hazard Detection and Avoidance (HD/A) hardware-in-the-loop scenarios. This year's completed research serves as a stepping stone towards developing a medium fidelity hardware-in-the-loop spacecraft relative navigation system for TRN and HD/A.

Background

LIDAR systems are the next step in improving spacecraft navigation due to the high information content delivered about a spacecraft's environment. One critical research challenge is economical localization and mapping that is central to transforming point cloud position data into accurate vehicle pose estimates, i.e. relative position and orientation. It is extremely difficult to get reasonable rate estimates, i.e. relative translational and rotational velocity, without any other sensor input because the environment in entry descent and landing (including small body proximity operation environment) is not instrumented with inertial sensors. While it is common to have other perception sensors, such as inertial measurement units (IMUs) and star trackers, to determine a terrain-relative navigation solution, significant work must be done to fuse the varying sensor information in a reliable manner. The state-of-the-art velocimeter LIDAR being investigated is capable of simultaneously generating point clouds (3D locations of objects), point-wise Doppler velocity measurements, a co-registered image stream, and an infra-red (IR) response of the environment from the sensor point of view. Newly derived mathematical models and preliminary experiments suggest that given only raw position and Doppler velocity measurements, a complete 6DOF relative pose and velocity can be estimated without any accompanying sensing mechanisms.

Approach and Results

To characterize the Aeva A2 velocity meter LIDAR prototype, the five measurement capabilities of the system were studied to establish means of registering each data stream with respect to each other. These five capabilities include: vision (RGB camera), depth (three dimensional position data), signal return intensity, doppler velocity, and surface reflectivity.

The vision capabilities of the system provide images at 1080p resolution (1920 x 1080) and a frame rate of 10 Hz. The camera origin and coordinate frame were determined to be non-coincidental with that of the LIDAR sensor. This results in the requirement of post-processing on the images captured by the system to allow for the projection of point cloud data onto the captured image. To perform this post-processing procedure, the translation vector and rotation matrix between the camera and LIDAR sensor are required. The translation vector and rotation matrix were computed using the given camera calibration parameters and a least squares approximation of points located in each coordinate frame.

The depth measurement capability was found to exhibit a behavior where the point cloud data captured was primarily contained in distinct non-moving radial bands. Investigation of these bands revealed that they were evenly spaced at all distances and provided a "weight averaged" mean location of the point cloud. More simply, a single object's point cloud data will appear in multiple radial bands, with the mean location derivable from the density of points in each band.

Investigation of the doppler velocity measurement capability revealed that at low-speeds the average point cloud velocity noise is consistently around 5 centimeters/second. The variation of the point cloud velocity was determined to be on the same order of magnitude, but with slightly higher values (between 7 and 11 centimeters/second). It was also observed that increasing the total velocity magnitude did not significantly increase the doppler velocity noise at low speeds.

To test the behavior of the intensity and reflectivity measurement capabilities, various test materials were selected that provide a wide range of intensity/reflectivity values. The investigation revealed that intensity values depend on the distance to and the orientation of the target, while the reflectivity values depend only on the orientation. This strongly implies that the LIDAR system is measuring both the specular and diffuse components of the intensity/reflectivity signal. Finally, it was determined that the position and velocity variation in a point cloud decreases as the intensity of the return signal increases.

With regards to testbed development, emulation robotics offers a convenient way to perform hardware-in-the-loop testing to aid in the creation and verification of navigation systems. The Land, Air, and Space (LASR) Laboratory at Texas A&M houses several robotics platforms and several additions and upgrades were completed throughout this year. Most notably, a brand-new 90'x60'x14' blacked out workspace with two (2) 1 Ton gantry systems, was constructed. Once this large space is outfitted with Vicon Motion capture system for truth data and robotics control system feedback, it will be one of the largest, most capable test beds for TRN experiments in the world.

Significance/Benefits to JPL and NASA

The characterization of the Aeva A2 velocimeter LIDAR and the development of various hardware and software testbeds over the past year has poised the research team to make significant strides towards the hardware-in-the-loop testing of the proposed navigation system for the upcoming year. Inherent parameters of the velocimeter LIDAR necessary for successful navigation filtering, such as position and velocity variance, measurement quantization, and calibration constants, were determined through rigorous testing. Without correct noise characteristics, resulting state estimates obtained through any kind of navigation filter can be subject to drift, bias, and over/underconfidence. To evaluate the efficacy of the velocimeter LIDAR in real-world applications, such as Terrain Relative Navigation (TRN) and Rendezvous, Hazard Detection/Avoidance (HD/A) and Proximity Operations, and Docking (RPOD), emulation robotics experiments have been designed which will be completed over the next year. To enable these demonstrations, several mechanical and software elements including a power distribution system for the LIDAR and accompanying electronics, real-time data acquisition software, and integration with existing robotic systems were developed over the course of the year. All of the work completed this year has primed the team from NASA/JPL and Texas A&M for creating an unprecedented end-to-end velocimeter LIDAR based spacecraft relative navigation system.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: sarah.urdahl@jpl.nasa.gov

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