National Aeronautics and Space Administration

Advanced Navigation for Future Mars Rotorcraft

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Program: Strategic Initiatives

Project Objective:

Provide a future Mars Science Helicopter with advanced navigation and safe landing capabilities for all terrain access

- Visual-inertial state estimation relative to the take-off point for flights over any type of terrain
- Onboard hazard detection and avoidance to enable autonomous safe landing in terrain with landing hazards
- Additional navigation capabilities required to enable high-priority, high impact science operations

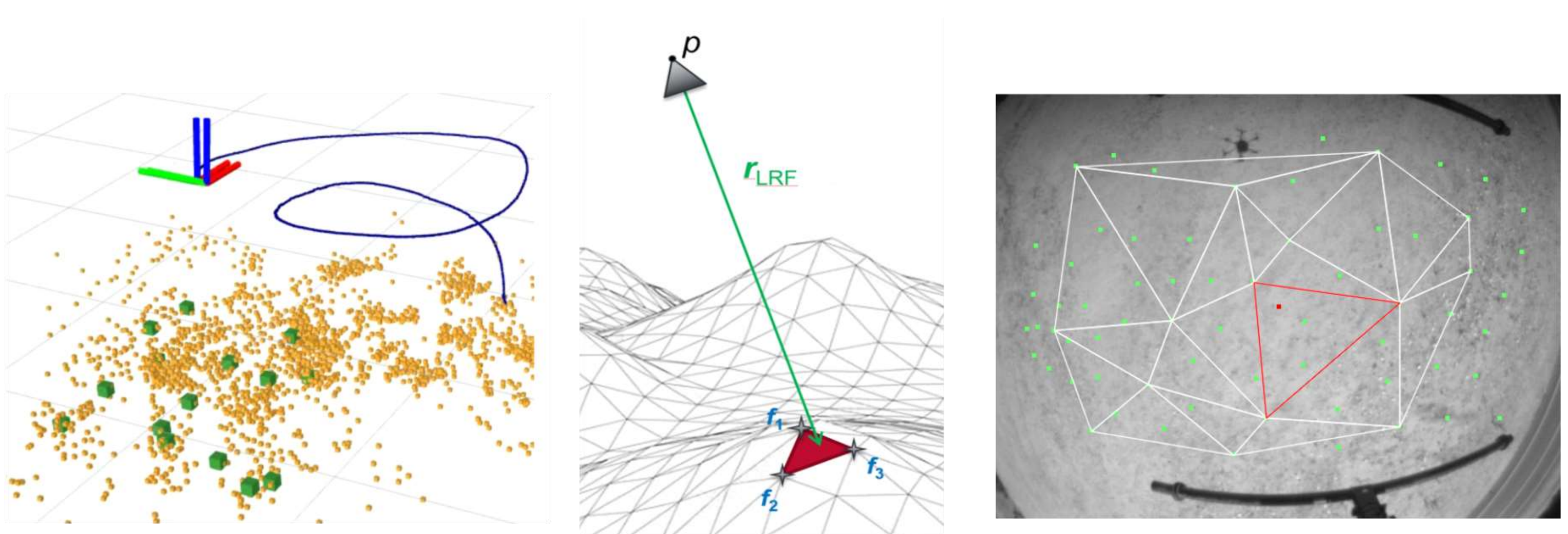
FY19 Results:

- Developed new visual-inertial odometry (VIO) algorithm that includes a laser range finder to overcome unobservable modes in traditional VIO algorithms, and provide the same level of robustness as the Mars Helicopter navigation approach (MAVeN). Sensors used: downward-looking camera (30 Hz), IMU (200 Hz), and a down-pointed single-beam laser range finder (5 Hz)
- Range-VIO algorithm was implemented and tested during a final test field test campaign in the Arroyo, running live on a computationally restricted embedded processing platform (Snapdragon 820) that is anticipated for a future Mars Science Helicopter avionics architecture
- Ongoing study of further improvement of robustness and accuracy of state estimates by adding auxiliary sensors (sun sensor, second forward looking camera)
- Developed new software interfacing framework for rapid deployment of navigation software on F-Prime and Robot Operating System (ROS) based platforms

Benefits to NASA and JPL:

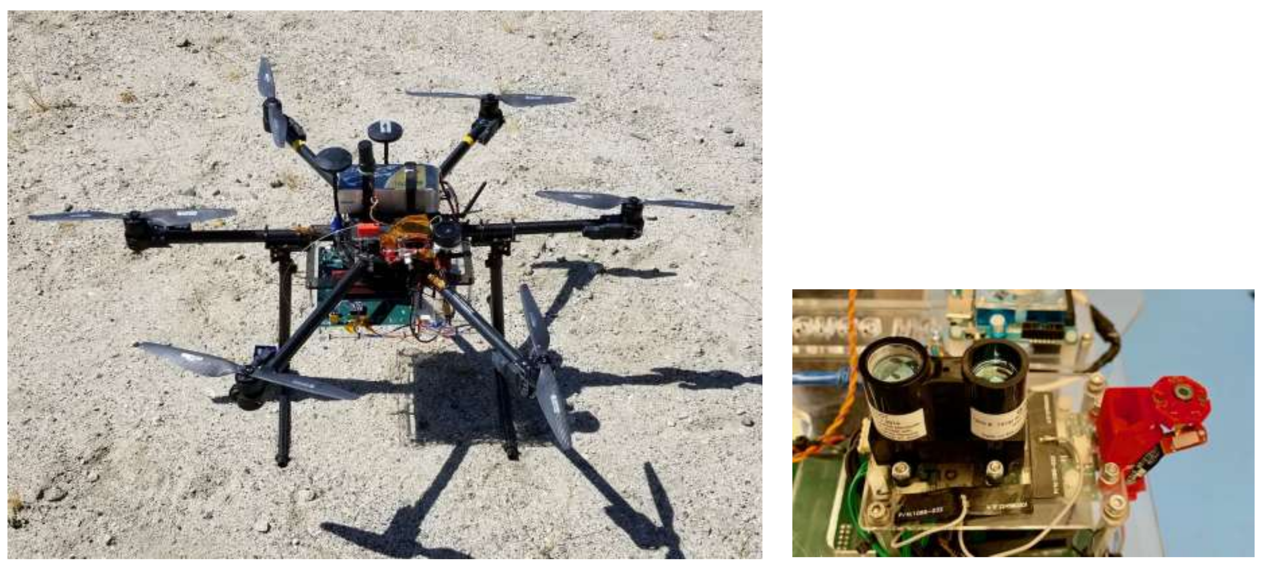
A highly capable Mars Science Helicopter (MSH) could have major impacts on future Mars exploration by enabling high priority investigations addressing all four of the top-level themes of Mars science (Life, Climate, Geology, and Prepare for Human Exploration). A science helicopter on Mars would extend the scope of possible science far beyond the range of a traditional lander or rover. Data could be gathered for extreme terrains a rover could not traverse, allowing for investigation of high priority science targets such as Recurring Slope Lineae (RSL) and active gullies. This includes visible imaging at much higher resolution than is possible from orbit, over much more area and in more extreme terrain than can be accessed by a rover, to establish regional geologic context, to map terrain layering that reveals climate history, to examine surface morphology and composition where rovers can't reach, and to assess the safety of candidate landing sites for future human exploration.

The development of the current Mars Helicopter is a crucial first step towards sending a rotorcraft capable of autonomous science investigations to Mars, but the navigation system of Mars Helicopter is limited for flights over benign, flat and level terrain. To enable the broad vision sketched above this task will develop autonomous navigation and safe landing technologies necessary for rotorcraft access to any terrain on Mars.

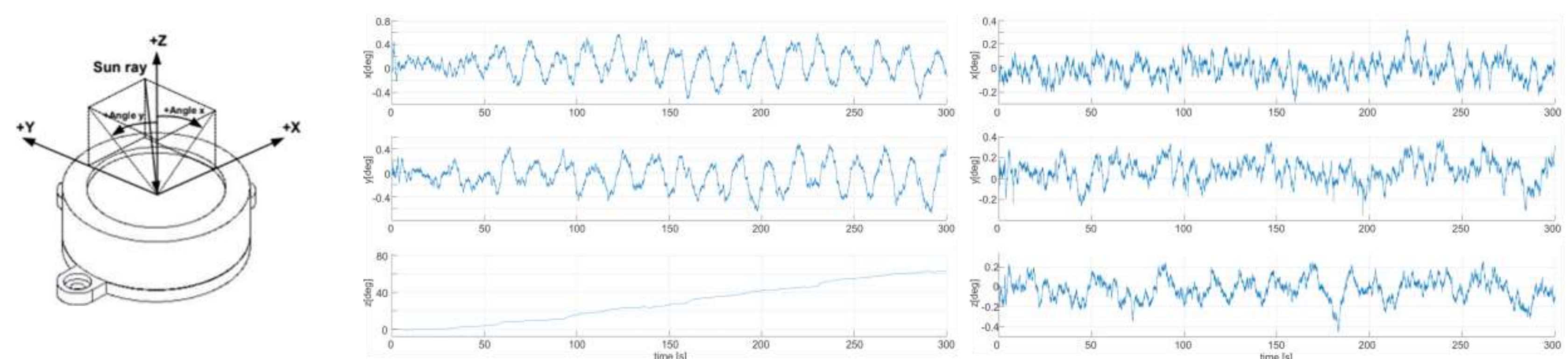


a b c

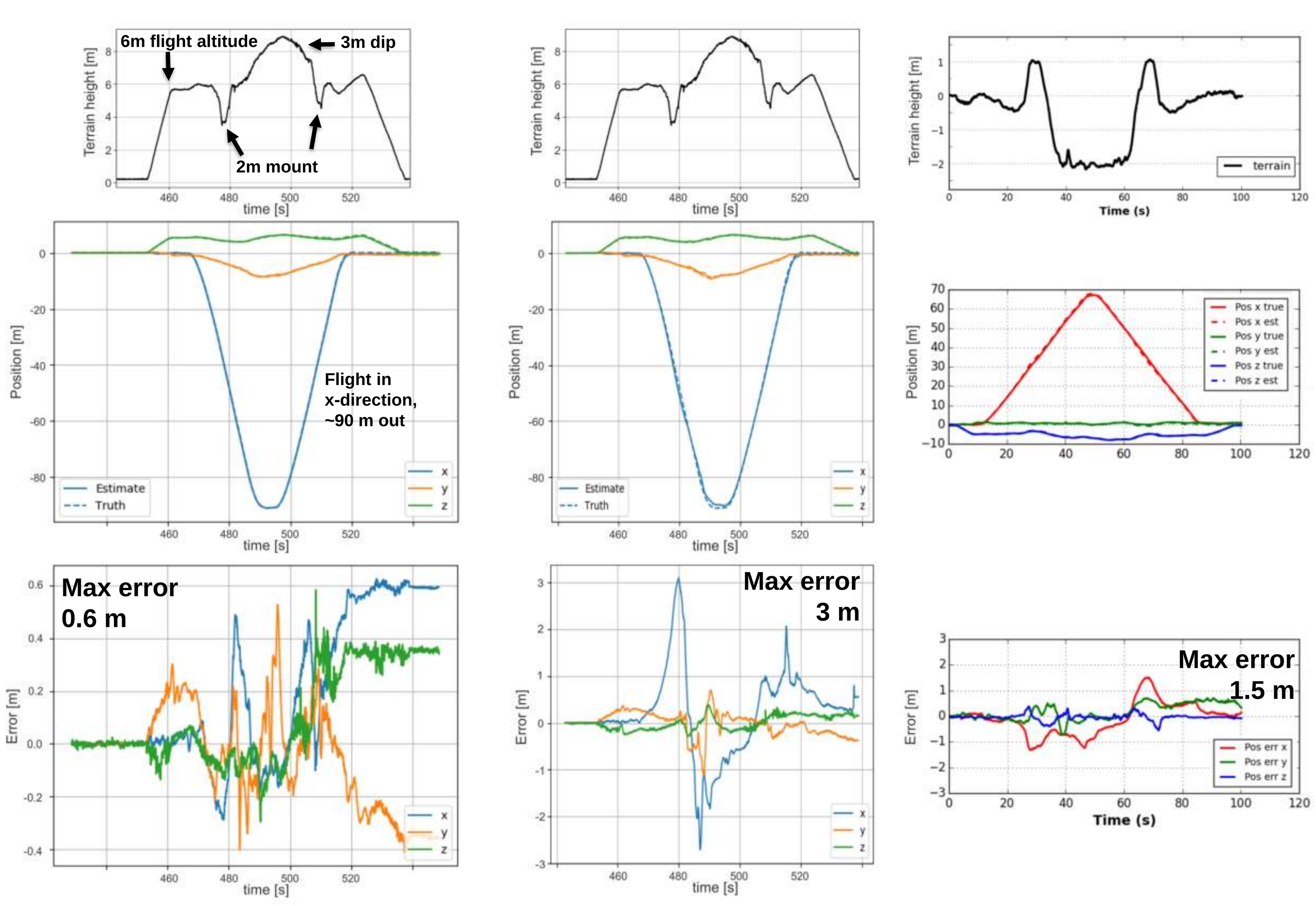
Range VIO state estimator: (a) State estimator in simulation; (b) range facet model for LRF incorporation; (c) State estimator running on real data: Image with overlaid tracked features, Delauny triangles illustrate image features used for state estimation. Red dot represents LRF impact point.



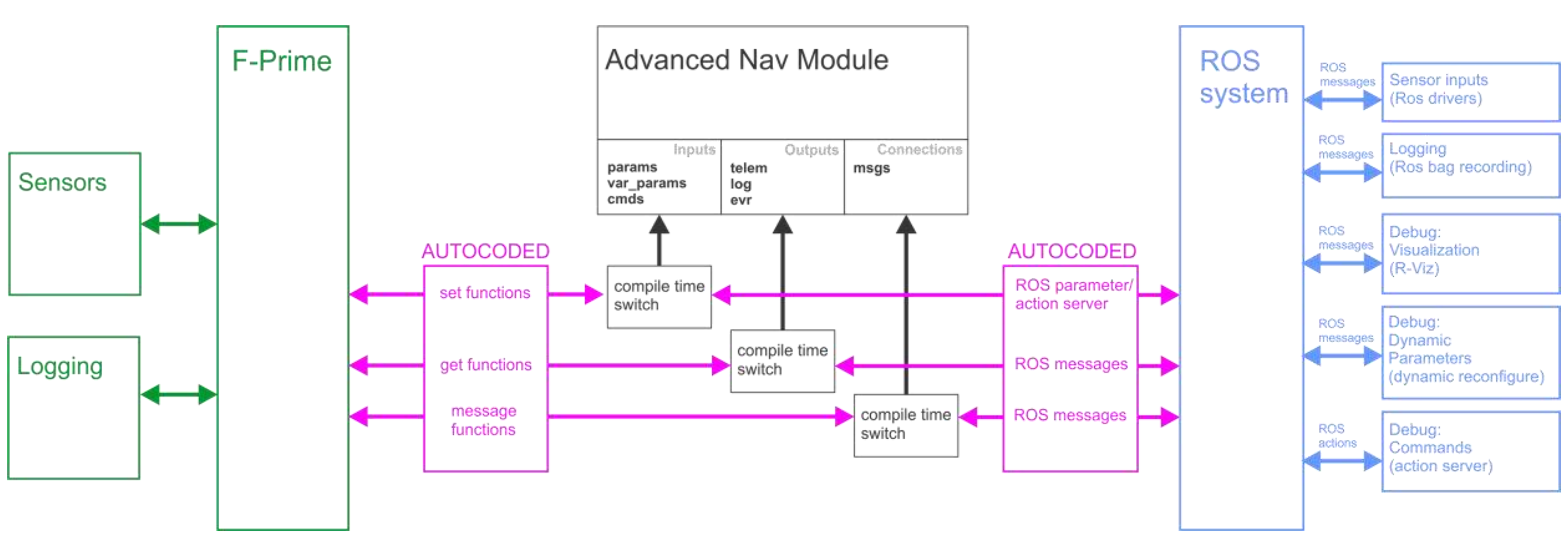
Left: TurboAce Infinity6 sUAS used for Arroyo field campaign to verify navigation approach; Right: On-board navigation sensor head with LRF (black cylinders) and cell-phone based navigation camera (to the right)



Using a sun sensor reduces yaw drift: Middle: Simulation experiment with extreme yaw drift during fast flight in a horizontal circular trajectory; Right: Yaw drift is reduced by incorporation of sun sensor measurement updates into the filter framework



Flight at constant altitude over terrain with 3D topology (out and back). Top row: measured LRF terrain distance over ground (left and middle) and calculated terrain height (right) for terrain topography indication. Position and position error of Range-VIO (left), VIO-only with unobservable modes (middle) and MAVeN estimator (right)



Rapid deployment F-Prime/ROS interfacing software framework

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Publications:

[1] J. Delaune, R. Brockers, D. Bayard, H. Dor, R. Hewitt, J. Sawoniewicz, G. Kubiak, L. Matthies, T. Tzanetos, J. (Bob) Balaram: Extended Navigation Capabilities for a Future Mars Science Helicopter Concept. Abstract accepted to IEEE Aerospace 2020.

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