National Aeronautics and Space Administration

Autonomous Approach and Landing on Small Bodies using SmallSats

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Program: FY21 R&TD Topics **Strategic Focus Area: Situational and self-awareness**

Objectives

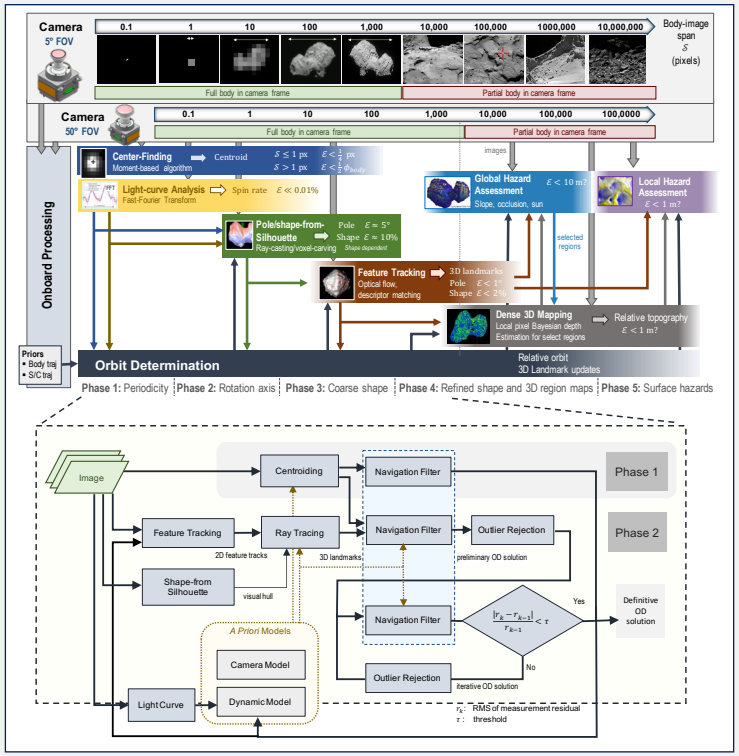
Develop algorithms to onboard **estimate** the **motion** and **shape of an unexplored body** during approach, map its **surface topography** and **assess hazards** for subsequent proximity operations, landing, and surface mobility, all while estimating the **relative spacecraft trajectory**.

Background

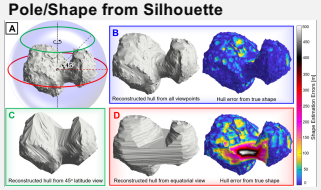
Autonomous systems need to *reason* about and *reconcile* onboard information to establish ***situational awareness*** before taking actions. This work establishes onboard and real-time knowledge for a traditionally ground-intensive operation that uses old information: the approach of and landing on a small unexplored body.

Approach

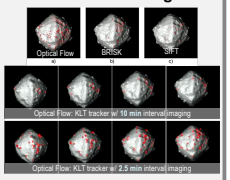
Multi-phase approach estimation pipeline using narrow and wide FOV cameras, and attitude estimation (via star tracking and inertial sensing)



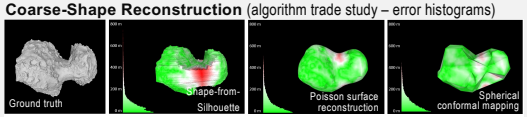
Pole/Shape from Silhouette



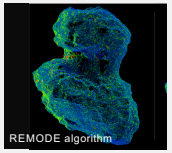
Feature Tracking



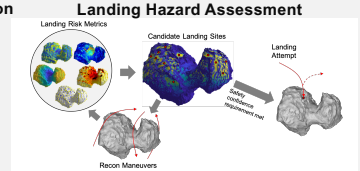
Coarse-Shape Reconstruction (algorithm trade study – error histograms)

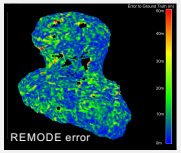


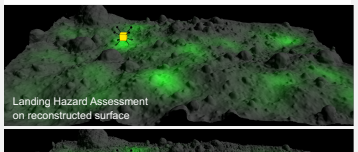
Dense Reconstruction

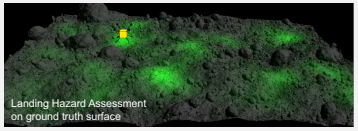


Landing Hazard Assessment









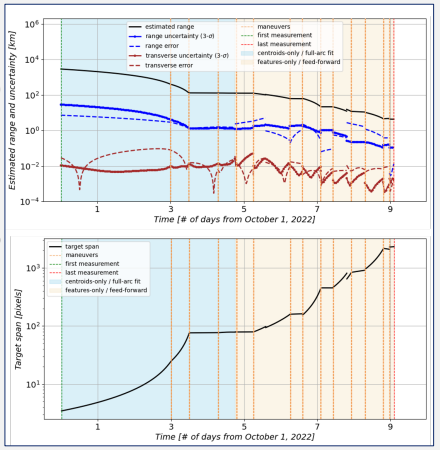
Simulated Artificial Body

Significance/Benefits to JPL and NASA

This is a foundational capability that would eventually enable greater to diverse small bodies at more affordable cost, initially leveraging SmallSats for NEOs and eventually enabling access to more distant small bodies. Targets include: asteroids, comets, centaurs, trans-Neptunian bodies, and small moons of outer planets. Autonomous exploration of small bodies using SmallSats would serve as a stepping stone toward more complex and challenging exploration of ocean worlds and outer planetary bodies.

Results

- Conducted a blind experiment approaching an unknown (simulated0 body from 3,000 km – 20 km
- Continued approach to hover position at 5 km
- Changed latitude to identify candidate landing sites
- Executed a close flyby to 60 m off the body for landing reconnaissance
- Developed algorithms to assess safe landing sites
- Used autonomy algorithms (left) to establish situational awareness throughout



Publications

1. S. Bandyopadhyay, et al., "Light-robust pole-from-silhouette algorithm and visual-hull estimation for autonomous optical navigation to an unknown body," submitted to Journal of Guidance, Control, and Dynamics
2. B. Jarvis, G. Choi, B. Hockman, B. Morrell, S. Bandyopadhyay, D. Lubey, J. Villa, S. Bhaskaran, D. Bayard, and I. Nesnas, "Coarse Mapping of Small Bodies," in *IEEE Robotics and Automation Letters*, vol. 6, no. 4, pp. 7089-7096, 2021
3. I. Nesnas, B. Hockman, S. Bandyopadhyay, B. Morrell, D. Lubey, J. Villa, D. Bayard, A. Osmundson, et al., "Autonomous Exploration of Small Bodies Toward Greater Autonomy for Deep Space Missions," Frontiers in Robotics and AI, 2021
4. B. Morrell, J. Villa, S. Bandyopadhyay, D. Lubey, B. Hockman, S. Bhaskaran, D. Bayard, and I, Nesnas, "Automatic Feature Tracking of Small Bodies for Autonomous Approach," AIAA ASCEND, 2020
5. J. Villa, B. Morrell, B. Hockman, A. Harvard, S. Chung, S. Bhaskaran, I. Nesnas, "Optical Navigation for Autonomous Approach of Small Unknown Bodies," 43rd Annual AAS GNC Conference, Breckenridge, Colorado, 2020
6. S. Papais, B. Hockman, S. Bandyopadhyay, R. Karimi, S. Bhaskaran, and I. Nesnas, "Architecture Trades for Accessing Small Bodies with an Autonomous Small Spacecraft," 2020 IEEE Aerospace Conference, 2020, pp. 1-20,
7. J. Villa, S. Bandyopadhyay, B. Morrell, B. Hockman, S. Bhaskaran, and I. Nesnas, "Optical Navigation for Autonomous Approach of Small Unknown Bodies," 2nd RPI Space Imaging, Saratoga Springs, NY, October 2019.

Clearance Number:
RPC/JPL Task Number: R20107

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