National Aeronautics and Space Administration

Radiometric Autonomous Navigation Fused with Optical for Deep Space Exploration

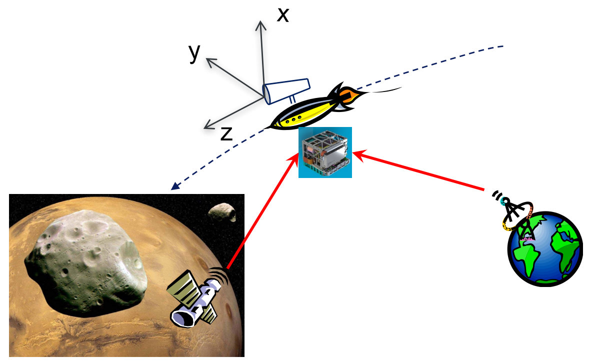
Principal Investigator: Todd Ely (392)

Ted Drain (392), Daniel Lubey (392), Jill Seubert (392)

Program: Strategic

Project Motivation & Objective: Autonomous navigation using combined radio and optical data yields robust system

- Onboard optical data processing proven capability with JPL's AutoNav software and demonstration on DS1 and use for Deep Impact and Stardust
- Robust autonomy requires fault tolerance that radio combined with optical provide naturally
  - Robotic exploration will need it for enhanced exploration
  - Human exploration will require it for safety
  - Fused data solution more accurate than individual data source solutions
- Advent of Deep Space Atomic Clock coupled with capable s/c radio enabling for collecting stable, precise one-way radiometric data onboard
- This tasks three-year objectives include:
  - Complete radiometric model and associated filter model development suitable for onboard deep space navigation processing. Conduct research on fusing radio and optical data for robust trajectory solutions.
  - Preliminary research into automated techniques to evaluate solution efficacy
  - Complete development of prototype onboard orbit determination software capable of processing radio and optical data and with flexible filtering capabilities



- Optical & radio data characteristics
  - Optical imagery most sensitive in onboard telescope (x, y) plane
  - Radio range & Doppler most sensitive along along line of sight to in-situ tracking s/c and/or Earth tracking station
- Optical and radio data complimentary and combined yield better solutions than separately and provide natural fault tolerance

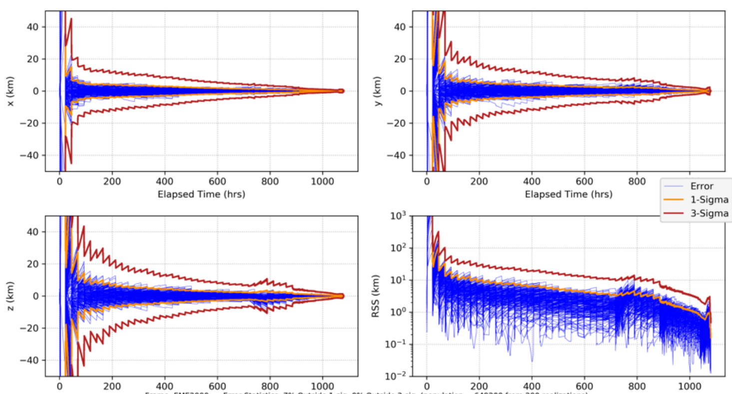


Figure 1. Mars approach and entry position errors with CPF-phase for only 2 hrs/day from DSS-65 and optical imaging of asteroids and Phobos and Deimos using onboard modeling and an iterated LKF with no smoothing.

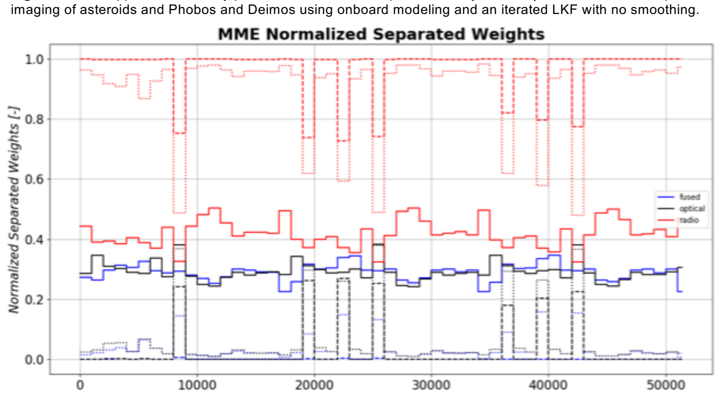


Figure 2. Gating network weights for a filter bank containing radiometric-only, optical-only, and fused filters. An unmodeled bias is included in the optical measurements on the order of 0.1 pix (solid), 1.0 pix (dotted), and 10.0 pix (dashed).

FY19 Results

- Developed simplified measurement and spacecraft dynamic models for onboard use and associated filter compensation techniques to ensure robust solutions
  - CPF-phase eliminated ionosphere delays from radio data, other delays accounted for with model predicts and filter compensation
  - Showed iterated linearized Kalman filtering without smoothing is sufficient – reduces onboard memory requirements
- Combining optical and CPF one-way phase yields better solution than either separately
  - Optical imaging of 37 main-belt asteroids, and Phobos and Deimos (would require gimbaled narrow angle camera)
  - 2 to 3 times improved accuracy with combined data vs separate and able to reduce needed DSN tracking by 92% for case examined
- Conducted preliminary investigation into filter bank methods for detecting solution anomalies resulting from measurement and/or dynamic modeling errors/changes with positive results
- Developed prototype orbit determination software (called AutoNav2.0) to replace OD in legacy AutoNav
  - Development Approach
    - To the extent possible, reuse Monte algorithms to improve maintainability
    - Being developed in ANSI C++
    - Follow flight software design rules – no dynamic memory, no real time interrupts, and no C++ exception handling
  - FY 19 development goals met
    - Implemented two main measurements types – optical and CPF-phase
    - Implemented square root information filter using a moving window batch processing algorithm (similar to that used on the legacy AutoNav system) and tested against real mission data using an MRO test case.
    - Developed a Python API to facilitate testing with Monte at the unit and system level,
    - Developed a second Python API that allows messages to be sent to and received from a running multi-threaded AutoNav simulation - facilitates flight-like testing via emulating a multi-threaded spacecraft CPU and message bus controlling the system.
    - Developed a modular logging system for debugging

Benefits to NASA and JPL

- Successful prototype for radio/optical AutoNav software system will yield a more robust onboard navigation system that could lead to wider use on a variety of deep space missions
- Enhance future missions by reducing ground operations, and/or DSN support.
- Enabling for robust, safe onboard navigation for future human exploration of the solar system

Publications

Ely, Todd A. et al. "Radiometric Autonomous Navigation Fused with Optical for Deep Space Exploration." AAS/AIAA Astrodynamics Specialist Conference, Portland, Maine, 2019.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr. Contact Info: Todd.A.Ely@jpl.nasa.gov, 818-393-1744

Poster No. RPC-121