The DPS (Deep-space Positioning System) Concept:

Automating Complex Navigation Operations Beyond the Earth


SCAN Workshop on Emerging Technologies for Autonomous Space Navigation
Session 3: Game-Changing Initiatives

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Problem 1: Where am I and which way do I go?

Two ways this is done in deep space...

1) A radio link with the Earth can be used to position a spacecraft to ~1km level in the inner solar system

2) Pictures of multiple asteroids can position a spacecraft to 10-100 km anywhere in the Solar System (as Deep Space 1 did in 1999)

The MarCO cubesats (pictured) carry a 0.5U radio and are planned to accompany the InSight Mars 2018 lander. Future versions could also include a camera and have the capacity to perform both of these navigation functions autonomously.
Problem 2: How do I navigate close to my target destination?

Only one practical way to do this... with optical navigation

Target positions are not usually known very well, pictures on approach, with background stars, allow for precise determination of the spacecraft position relative to the target.

This enables very accurate imaging of the body during high speed flybys.

This was done autonomously onboard Deep Space 1 at comet Borrelli in 2001 (pictured).
NASA/JPL experience with optical navigation

A decade of success with AutoNav (software)

DS1 at Borrelly Sept., 2001

Deep Impact at Tempel 1 July 2005

Deep Impact Hartley 2, Nov. 4, 2010


Stardust Tempel 1, Feb 14, 2011
Comet impact with autonomous optical navigation
Deep Impact mission at Tempel 1, July 4, 2005 – view from the impactor

Impactor stage operated autonomous navigation for 2 hours prior to impact

Performed completely automated maneuvers at 90, 35 and 12.5 minutes before impact
Deep Impact Autonomous Activities

**ADCS aligns ITS Control frame with Relative velocity E-5 min**

**Tempel 1 Nucleus**

**ADCS aligns shield with relative velocity**

**ITM-3**
- E-12.5 min

**ITM-2**
- E-35 min

**ITM-1**
- E-90 min

**AutoNav/ADCS Control E-2 hr**

**Impactor Release E-24 hours**

**Flyby S/C Science And Impactor Data**

**Flyby S/C Deflection Maneuver Release + 12 min (101 m/s)**

**TCM-5 at E-30 hours**

**Action is from right to left**

- 2-way S-band Crosslink
- 500 km
- Shield Attitude through Inner Coma
- ADCS aligns shield with relative velocity
- Flyby S/C Science Data Playback to 70-meter DSS
- Shield Attitude Entry
- Impact!
- Flyby S/C Science Real-Time Data
- Look-back Imaging E+45 min
- 64 kbps
- 3 = 0.6 mrad
AutoNav on the Flyby Spacecraft
Observing/Capturing the impact
Inspecting the damage five-and-a-half years later…
AutoNav on Stardust used again to image the impact site on Tempel 1

Faint shadow of an ~50 m crater at the impact site

Pre-impact, July 4, 2005
Post-impact, Feb 14, 2011
Future missions and challenges for a DPS

Earth independent precise approach, entry and landing on Mars (or the Moon) would require the onboard navigation system (DPS) to know landmarks on the surface, and guide the vehicle relative to them.

Mars has the additional benefit of having two ideal natural satellites (navigation beacons) in orbit around it. MRO demonstrated this in 2005.

Earth return from Mars or the Moon for crewed or sample return missions will require a contingency onboard navigation system. Earth limb tracking is difficult due to atmospheric haze. DPS could solve this problem by observing artificial satellites that are very dim, but with well known positions.
Landing on (or touch sampling) a small body (a simulation)
Multiple layers of landmarks are necessary at ever increasing resolution to land with precision

Landmarks are shown as faint red squares with yellow numerical labels

Scale of the images changes by x1000 over the course of the descent.
Future Missions

Enceladus is offering free (dirty) water samples for any mission that can navigate the plumes

A mission to Enceladus to search for potential life-habitats would need precision *in situ* navigation to maintain low-altitude periodic orbits around Saturn for multiple sampling flyby passes through the plumes
A concept for a flight to Enceladus using DPS

A delicate gravity dance – and DPS knows the dance
The Implementation Problem
Getting beyond point-solutions for every mission

AutoNav has flown three times (Deep Space 1, Stardust, Deep Impact)

Each flight was a custom application requiring full test and validation activities

Each flight had moderate to severe software integration “issues”

Substantial cost and risk was incurred by a unique flight-by-flight instantiation
The proposed solution
DPS: Deep Space Positioning System

• Develop a multi-use instrument capable of:
  – Navigation measurement (optical and radio)
  – Data processing and orbit determination
  – Path planning and maneuver estimation
  – Course correction implementation

• Make the hardware and software generally applicable enough that:
  – Only moderate (if any at all) modifications would be required for each particular mission
Elements of the DPS concept
Camera, radio, clock, steering actuators and flight software

**Integrated DPS Instrument**

- **MRO OpNav Camera**
  2.1° FOV high-sensitivity camera

- **STMD Deep Space Atomic Clock**
  Provides “DSN-Quality” frequency and time reference for one-way radio

- **OCO-3 Actuators**

- **ASC Star-tracker**

- **Iris Software Defined Radio**
  Extracts one-way radio observables and hosts AutoNav FSW

- **Deep Impact AutoNav**
  Provides autonomous in situ navigation (via optical and/or radio)
Flight Options
One size will never fit all

Deep Space 1, Stardust, Deep Impact Implementation, appropriate for MSR rendezvous

Proposed Comet Surface Sample Return, lunar or Mars lander

Potential Earth return vehicle (Moon or Mars, robotic or crewed) Implementation

Potential cubesat implementation
Status, Future, Conclusions

• The APIC instrument (the DPS camera) is being developed by NASA for a future Io Observer mission concept (New Frontiers 5)

• A number of missions are considering using APIC and DPS prior to the potential flight of the Io Observer concept

• A 2U “mini-APIC” is also being developed (with lower camera resolution)

• NASA has patented the DPS concept, and discussions are ongoing with the commercial sector for its use for crewed flight

• At some point in the future, all missions beyond Earth will navigate themselves – with something like DPS, the Deep-space Positioning System