National Aeronautics and Space Administration

Pulsar Based Navigation for Deep Space and Planetary Missions

Principal Investigator: David S. Bayard (343)
Co-Investigators: Walid A. Majid (335), Po-Ting Chen (343), Lincoln J. Wood (392)
Prof. Jason L. Speyer, UCLA Dept. of Mechanical and Aerospace Engineering
Ben Dunst, Luis Andrade, UCLA Graduate Students

Program: R&TD Topic

PROJECT OBJECTIVE

Develop new concepts, algorithms and analysis tools to support pulsar-based deep space navigation

- **Investigate alternative clocks for pulsar navigation, including USO and Cesium atomic clocks, and pulsar-aided timing to improve clock accuracy**
- **Develop special covariance analysis tools (CAT) suitable for evaluating long-horizon navigation performance (10-15 years)**
- **Apply CAT tools to analyzing PNAV performance trade-offs - pulsar observing time, pulsar receiver SNR, and average mission thruster activity**

BACKGROUND

- **Pulsar-Based navigation is similar to the idea of GPS-based navigation but it operates in deep space with X-Ray Pulsars playing the role of GPS satellites**
- **Called out as a key technology in 2015 NASA Communication and Navigation Systems Roadmap**

BENEFITS TO NASA and JPL

- **Provides autonomous deep space navigation with minimal ground resources**
- **Position knowledge independent of distance to Earth**
- **Ideal for deep space and interstellar missions**
- **Improvement to DSN accuracy over distances greater than 5 AU (orbit of Jupiter)**
- **Reduced reliance and demand on the DSN**

NEW TECHNOLOGY

NTR # 50323 - *An Algorithm for Pulsar-Based Deep Space Navigation*

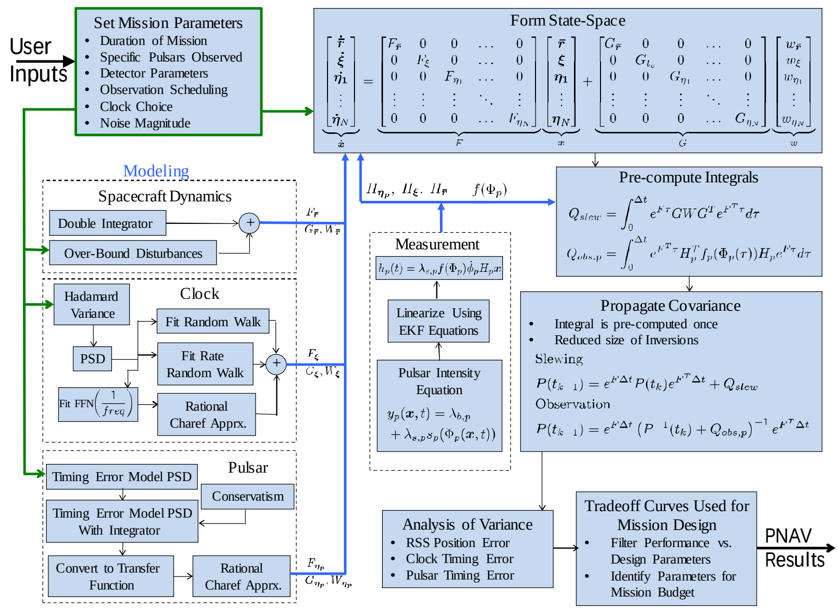
NTR # 50984 - A Particle Filtering Algorithm for Resolving Integer Ambiguity in Pulsar-Based Navigation

PUBLICATIONS

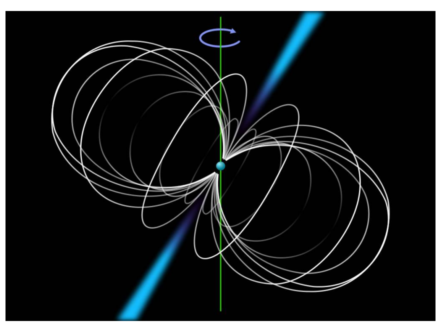
- ***Frequency Stability Analysis of Pulsar-Aided Clocks*** **NAVIGATION, Vol. 66, No. 3, 2019**
- ***Autonomous Spacecraft Navigation Using X-Ray Pulsars and Multirate Processing*, J. Guidance, Control, and Dynamics, Vol. 40, No. 9, Sept 2017**
- ***Aspects of Pulsar Navigation for Deep Space Mission Applications*, submitted J. Astronautical Sciences**
- ***Experimental Verification of a Pulsar-Based Positioning System Using L-Band Measurements*, submitted J. Guidance Control and Dynamics**

FY18/19 Results

Pulsar Navigation Covariance Analysis Tool

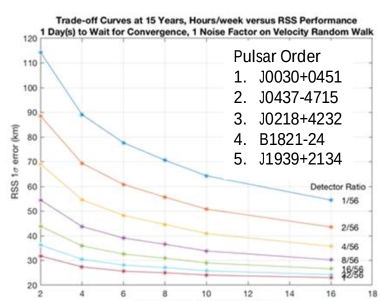


High Fidelity Clock and Pulsar Drift Modeling



- **High fidelity clock and pulsar drift models for more accurate long-term analysis**
  - **Developed rational approximation of fractional noise for both pulsars and clocks to allow more realistic behavioral models over 15 year horizon**
- **Closed-form integrals in covariance analysis to significantly reduce computation time**
  - **15 year analysis now performed in 2 min**
- **Analyzed AUTONOMOUS CRUISE for long-duration missions**

Performance for 15 Year Autonomous Cruise (no DSN)



Initial Conditions
- Initial Position Error (x, y, z) 1-σ : 50 km
- Initial Velocity Error (x, y, z) 1-σ : 1 m/s
- Initial Clock (USO) Bias Error 1-σ : 50 μs
- Initial Clock (USO) Bias Rate Error 1-σ : 1×10^{-10} s/s
- Initial Pulsar (all) Bias Error 1-σ : 5 μs

Noise Parameters
- Velocity Random Walk PSD σ^2 : $(4.0739\times10^{-10}\ m^2/s) \times \xi^2$
  - Scaled by ξ^2 : ξ = [1, 2, 4, 8, 16]

Pulsar Observation
- Duration of Observation : 30 (minutes)
- Time Allocated to Slewing : 10 (minutes)
- Hours/week of Observations and Slewing (combined)
  - [2, 4, 6, 8, 10, 16] Hours/week

Position Error (km): RSS 1-sigma

15 Year Mission, Noise=1*Cassini

	Weekly Observing Hours			
S/N	2	4	8	16
1/56	114.38	89.09	70.62	54.45
8/56	54.54	43.75	36.56	30.26
32/56	36.25	30.49	27.12	24.28
1	31.83	27.41	25.03	23.07

Velocity Error (m/s): RSS 1-sigma

15 Year Mission, Noise=1*Cassini

	Weekly Observing Hours			
S/N	2	4	8	16
1/56	0.0343	0.031	0.0282	0.0255
8/56	0.0264	0.0233	0.0211	0.0191
32/56	0.0223	0.0192	0.0174	0.0158
1	0.0209	0.0177	0.0161	0.0146

Blue Box: Shows PNAV has accuracy of 89 km and 3.1 cm/sec for 15 year cruise (no DSN) assuming USO clock, Cassini-level thruster disturbances, 1/56 NICER photon collection area, and 4 hrs/wk pulsar observations

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr. Contact Information:
David S. Bayard
818-354-8208
david.bayard@jpl.nasa.gov

Poster No. RPC-174