

ity to integrate the proposed methodology with both heritage and anticipated future plasma particle spectrometer designs is demonstrated (with sufficiently detailed design analysis to advance

TRL) to show specific science relevancy with future HSD (Heliophysics Science Division) solar-interplanetary, planetary missions, sounding rockets and/or CubeSat missions.

This work was done by Adolfo Figueroa-Vinas of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16455-1

➤ Powered Descent Guidance With General Thrust-Pointing Constraints

NASA's Jet Propulsion Laboratory, Pasadena, California

The Powered Descent Guidance (PDG) algorithm and software for generating Mars pinpoint or precision landing guidance profiles has been enhanced to incorporate thrust-pointing constraints. Pointing constraints would typically be needed for onboard sensor and navigation systems that have specific field-of-view requirements to generate valid ground proximity and terrain-relative state measurements.

The original PDG algorithm was designed to enforce both control and state constraints, including maximum and minimum thrust bounds, avoidance of the ground or descent within a glide slope cone, and maximum speed limits. The thrust-bound and thrust-pointing constraints within PDG are non-convex,

which in general requires nonlinear optimization methods to generate solutions. The short duration of Mars powered descent requires guaranteed PDG convergence to a solution within a finite time; however, nonlinear optimization methods have no guarantees of convergence to the global optimal or convergence within finite computation time.

A lossless convexification developed for the original PDG algorithm relaxed the non-convex thrust bound constraints. This relaxation was theoretically proven to provide valid and optimal solutions for the original, non-convex problem within a convex framework. As with the thrust bound constraint, a relaxation of the thrust-pointing constraint also provides a lossless convexifi-

cation that ensures the enhanced relaxed PDG algorithm remains convex and retains validity for the original non-convex problem. The enhanced PDG algorithm provides guidance profiles for pinpoint and precision landing that minimize fuel usage, minimize landing error to the target, and ensure satisfaction of all position and control constraints, including thrust bounds and now thrust-pointing constraints.

This work was done by John M. Carson III, Behcet Acikmese, and Lars Blackmore of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47853.

➤ X-Ray Detection and Processing Models for Spacecraft Navigation and Timing

Combining different pulsar measurements provides accurate overall navigation for deep space vehicles.

Goddard Space Flight Center, Greenbelt, Maryland

The current primary method of deep-space navigation is the NASA Deep Space Network (DSN). High-performance navigation is achieved using Delta Differential One-Way Range techniques that utilize simultaneous observations from multiple DSN sites, and incorporate observations of quasars near the line-of-sight to a spacecraft in order to improve the range and angle measurement accuracies.

Over the past four decades, x-ray astronomers have identified a number of x-ray pulsars with pulsed emissions having stabilities comparable to atomic clocks. The x-ray pulsar-based navigation and time determination (XNAV) system uses phase measurements from these sources to establish autonomously the position of

the detector, and thus the spacecraft, relative to a known reference frame, much as the Global Positioning System (GPS) uses phase measurements from radio signals from several satellites to establish the position of the user relative to an Earth-centered fixed frame of reference. While a GPS receiver uses an antenna to detect the radio signals, XNAV uses a detector array to capture the individual x-ray photons from the x-ray pulsars. The navigation solution relies on detailed x-ray source models, signal processing, navigation and timing algorithms, and analytical tools that form the basis of an autonomous XNAV system.

Through previous XNAV development efforts, some techniques have

been established to utilize a pulsar pulse time-of-arrival (TOA) measurement to correct a position estimate. One well-studied approach, based upon Kalman filter methods, optimally adjusts a dynamic orbit propagation solution based upon the offset in measured and predicted pulse TOA. In this delta position estimator scheme, previously estimated values of spacecraft position and velocity are utilized from an onboard orbit propagator. Using these estimated values, the detected arrival times at the spacecraft of pulses from a pulsar are compared to the predicted arrival times defined by the pulsar's pulse timing model. A discrepancy provides an estimate of the spacecraft position offset,

since an error in position will relate to the measured time offset of a pulse along the line of sight to the pulsar. XNAV researchers have been developing additional enhanced approaches to process the photon TOAs to arrive at an estimate of spacecraft position, including those using maximum-likelihood estimation, digital phase locked loops,

and “single photon processing” schemes that utilize all available time data associated with each photon. Using pulsars from separate, non-coplanar locations provides range and range-rate measurements in each pulsar’s direction. Combining these different pulsar measurements solves for offsets in position and velocity in three dimensions, and pro-

vides accurate overall navigation for deep space vehicles.

This work was done by Suneel Sheikh of ASTER Labs, Inc., John Hanson of CrossTrac Engineering, Inc., and Paul Graven of Cateni, Inc. and Microcosm, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16116-1