Goddard Space Flight Center
Greenbelt, Maryland 20771

Technical Support Package

Advanced Spacecraft Navigation and Timing Using Celestial Gamma-Ray Sources

NASA Tech Briefs
GSC-16737-1

National Aeronautics and
Space Administration

Technical Support Package

for

Advanced Spacecraft Navigation and Timing Using Celestial Gamma-Ray Sources

GSC-16737-1

NASA Tech Briefs

The information in this Technical Support Package comprises the documentation referenced in **GSC-16737-1** of *NASA Tech Briefs*. It is provided under the Commercial Technology Program of the National Aeronautics and Space Administration to make available the results of aerospace-related developments considered having wider technological, scientific, or commercial applications. Further assistance is available from sources listed in *NASA Tech Briefs* on the page entitled "NASA's Technology Transfer Program."

For additional information regarding research and technology in this general area, contact:

Goddard Technology Transfer Office
Mail Code 504
Goddard Space Flight Center
Greenbelt, MD 20771

Telephone: (301) 286-7960

Advanced Spacecraft Navigation and Timing Using Celestial Gamma-Ray Sources

Brief Abstract

ASTER Labs' Advanced Spacecraft Navigation and Timing using Celestial Gamma-Ray Sources is a novel relative navigation technology for deep-space exploration using measurements of celestial gamma-ray sources. This new Gamma-ray source Localization-Induced Navigation and Timing, or GLINT, concept incorporates existing designs of autonomous navigation technologies and merges these with the developing science of high-energy sensor components. This new enabling technology for interplanetary self-navigation could provide important mission enhancements to planned operational and discovery missions. It has the potential to decrease the overall operations cost of exploration missions, specifically by increasing the onboard navigation and guidance capabilities and reducing the risk of uncertainty of providing these vehicles the freedom to explore those areas that are most interesting. The Phase I project developed the necessary integration algorithms and hardware requirements, and determined system performance for NASA's exploration applications. Performance evaluations demonstrated that GLINT can achieve position determination with sub-kilometer accuracy. Specific potential applications envisioned are: support for the Deep Space Network, improved high-energy celestial source analytics and detector technologies, development of relative navigation capabilities using gamma-ray sources, space weather research and warning, space level terrestrial nuclear detection, back up navigation for commercial satellites, Global Positioning System (GPS) support for Department of Defense satellites, and space and terrestrial detectors and dosimeters.

Section I — Description of the Problem

We have developed a new, novel spacecraft navigation system that uses gamma-ray photons from distant celestial gamma-ray bursts to continually determine the three-dimensional position and velocity of the vehicle. The concept provides a measure of relative position along the line-of-sight to a celestial source based upon the difference in the arrival time of the burst at the spacecraft's location with respect to a reference location. This measurement can be computed at any location in the solar system and beyond, wherever the spacecraft and a reference station can detect the same burst and share their burst reception information. Therefore with these on-going bursts from all directions of the sky, navigation solutions can be continuously determined and updated while on interplanetary cruise, or in orbit about a destination planetary body, including asteroids.

The gamma-ray burst-based GLINT technology presents significant performance enhancement and risk reduction over current navigation systems and provides new capabilities to augment mission goals throughout the solar system. Gamma-ray detectors are currently found on almost all deep space missions, and science missions in Earth orbit. Many systems are continuing to actively collect photon data. While GRB sources are non-repeating and non-periodic, their flux intensities are much higher than most other high-energy celestial sources, providing well-defined temporal and morphological profile characteristics for time alignment. The GLINT system is implementable anywhere celestial gamma-ray sources can be detected, and these sources are typically detectable above cosmic background levels, as their peak intensities are detectable in the tens of keV to 1 GeV and higher energy bands.

Our analysis demonstrated achievable TDOA accuracies on the order of a fraction of a millisecond, even when constrained by current mission detector and Interplanetary Network (IPN) localization limitations.

Section II — Technical Description

A. Purpose and description of the innovation: For spacecraft vehicles venturing into deep space, current navigation methods require frequent interaction and communication with Earth stations, significantly increasing mission cost. GLINT has proven the technical feasibility of this new alternative navigation and timing solution that has a high degree of accuracy and will transform the future of space vehicle exploration by alleviating the operational burden on the Deep Space Network (DSN), increasing autonomy, and reducing mission risk.

B: Identification of methodology steps: GLINT utilizes existing celestial GRBs with known localizations, which are sufficiently abundant and frequent for deep space navigation use. By comparing the burst arrival times between two vehicles, a time-difference-of-arrival measurement is made, and accurate ranging between these spacecraft is used to reduce the navigation uncertainty of the remote vehicle.

C. Functional operation: Detailed systems engineering was based on sets of requirements for the operational system. Operation uses on-board data processing for full autonomy and ground-based processing with data sent to ground control station. Results of a software simulation of the navigation algorithm show GLINT can operate independently of the DSN and achieve l00s of meters of position accuracy. Operating cooperatively with DSN, reduced tracking requirements can be attained. Error estimates can be further improved by reducing the covariance uncertainty.

D. Alternate embodiments of innovation: There are currently no known alternate embodiments of the innovation described herein.

E. Supportive theory: The innovative theory supporting GLINT is based on an inversion of the lPN's burst position localization method.

F. Engineering specifications: Primary engineering components include gamma-ray detectors with fine timing resolution, RF antennae for telemetry of collected data, and an advanced GLINT timing circuit.

G. Peripheral Equipment: GLINT does not require peripheral equipment.

H. Maintenance, reliability, safety factors: Aside from the synchronization of onboard spacecraft clocks for error reduction, no maintenance, reliability or safety factor issues.

Section III — Unique or Novel Features of the Innovation

A. Novel or unique features: We developed a new, novel spacecraft navigation system that uses gamma-ray photons from distant celestial gamma-ray bursts to continually determine the three-dimensional position and velocity of the vehicle.

B. Advantages of innovation: The concept provides a measure of relative position along the line-of-sight to a celestial source based upon the difference in the arrival time of the burst at the spacecraft's location with respect to a reference location. This measurement can be computed at any location in the solar system and beyond, wherever the spacecraft and a reference station can detect the same burst and share their burst reception information. GLINT presents significant performance enhancement and risk reduction over current navigation systems and provides new capabilities to augment exploratory mission goals throughout the solar system. Gamma-ray detectors are currently found on almost all deep space missions, and science missions in Earth orbit.

C. Development of new conceptual problems: While GRB sources are non-repeating and non-periodic, their flux intensities are much higher than most other high-energy celestial sources, providing well-defined temporal and morphological profile characteristics for time alignment. Average burst detection frequency rates (-t-2 bursts/day) of current gamma-ray missions are capable of supporting GLINT operation. The GLINT system is implementable anywhere celestial gamma-ray sources can be detected, and these sources are typically detectable above cosmic background levels, as their peak intensities are detectable in the tens of keV to t GeV and higher energy bands.

D. Test data and source of error: Numerous previously-detected bursts, observed by two or more spacecraft in the Interplanetary Network, have been processed using both public and private time-tagged photon event data. Error sources include gamma-ray source errors (burst duration, fluctuation power spectrum, intensity, and source localization accuracy, burst models, periodic source stability and timing models), Interplanetary Network and detector errors (detectors, photon detection and timing resolution, source direction finding, and electronic noise), navigation component errors (on-board oscillator or clock stability, filter models), and system level errors (orbit propagation, unknown perturbations, time synchronization, time and reference frame errors (with relativistic effect considerations), processor limitations, communication system limitations, and source distribution).

E. Analysis of capabilities: The concept demonstrated the feasibility to measure time-difference-of-arrival of gamma-ray photon data observed by two or more spacecraft to sub-bin (-t ms) accuracy. Current detector capabilities highlighted the potential to achieve nanosecond timing of individual photons, yielding potential systematic TDOA's at the 100-nanosecond to few-microsecond level. A Kalman filter navigation simulation demonstrated the ability to augment the Deep Space Network, attaining 100s of meters of position accuracy and significantly reducing tracking requirements.

F. Any re-use or re-engineering of existing code?: Software tools used in processing photon event data and performing all necessary spacecraft clock and ephemeris time scale and reference frame conversions were produced specifically for the GLINT concept by the GLINT team.

Section IV —

Potential Commercial Applications

The developed technology will be applicable to multiple NASA exploration mission goals, including those to the Moon, Mars, asteroids, and missions beyond Jupiter. GLINT will provide current support to the NASA DSN, by reducing DSN tracking requirements. It will enhance DSN's infrastructure capability for increased commercial space industry utilization. The photon timing system provides relative navigation capabilities and improved capabilities for space weather detection and timing. GLINT's timing and energy board has the potential for miniaturization and use as a dosimeter by spacecraft for safe operation and astronauts while inside a space vehicle or during extra-vehicular activities in space or on a planetary surface. GLINT's high-energy photon detection will also support several non-NASA application areas. It can provide primary and back-up navigation solutions for commercial space vehicles.

For DoD, GLINT can provide an effective method to support the accurate localization of terrestrial nuclear detonations. For GPS satellites, it can support backup navigation if needed in the event that the ground system surveillance segment is compromised. Due to GLINT's ability to autonomously navigate, it can support the cross-link network of a constellation of communication or science satellites. GLINT has the capability for high-energy photon detection, which can be used in dosimeters and detectors on Earth in commercial industry sectors such as the medical field, scientific research, nuclear power, first responders, and security. Similar systems would be DSN, Optical Imaging, Differential One Way Ranging, GPS, radiometric tracking and ground-based radar.