Scope Title
Guidance, Navigation, and Control (GNC) Sensors and Actuators

Scope Description:

NASA seeks innovative, groundbreaking, and high-impact developments in spacecraft guidance, navigation, and control (GNC) technologies in support of future science and exploration mission requirements. This subtopic covers mission-enabling technologies that have significant size, weight and power, cost, and performance (SWaP-CP) improvements over the state-of-the-art commercial off-the-shelf (COTS) capabilities in the areas of (1) spacecraft attitude determination and control systems, (2) absolute and relative navigation systems, (3) pointing control systems, and (4) radiation-hardened GNC hardware.

Component technology developments are sought for the range of flight sensors and actuators required to provide these improved capabilities. Technologies that apply to most spacecraft platform sizes will be considered.

Advances in the following areas are sought:

1. Spacecraft attitude determination and control systems: Sensors and actuators that enable <0.1-arcsecond-level pointing knowledge and arcsecond-level control capabilities for large space telescopes, with improvements in SWaP requirements.
2. Absolute and relative navigation systems: Autonomous onboard flight navigation sensors and algorithms incorporating both spaceborne and ground-based absolute and relative measurements. Special considerations will be given to relative navigation sensors enabling precision formation flying, astrometric alignment of a formation of vehicles, and other GNC techniques for enabling the collection of distributed science measurements. In addition, flight sensors that support onboard terrain relative navigation for landing and sample return capabilities are of interest.
3. Pointing control systems: Mechanisms that enable milliarcsecond-class pointing performance on any spaceborne pointing platforms. Active and passive vibration isolation systems, innovative actuation feedback, or any such technology that can be used to enable other areas within this subtopic applies.
4. Radiation-hardened GNC hardware: GNC sensors that could operate in a high-radiation environment, such as the Jovian environment.
5. Increasing the fundamental precision of gyroscopes and accelerometers that utilize optical cavities could
benefit autonomous navigation and open up new science possibilities. Two strategies may be pursued to increase the precision. First, can the scale factor be increased without a concomitant increase in the quantum noise? Possible approaches include but are not limited to: (a) the use of fiber optics to increase cavity length without increasing SWaP, and (b) exploitation of the degeneracies known as exceptional points (EPs) that occur in non-Hermitian systems. Prominent examples of such systems include parity-time symmetric systems and cavities containing a fast-light medium. It remains to be seen, however, whether the boost in scale factor near an EP can result in increased precision or is entirely counteracted by additional quantum noise. Proposals are sought that seek to answer this question through theoretical or experimental means in passive and active systems, including continuous-wave and pulsed lasers. Second, can the quantum noise be reduced without a concomitant reduction in scale factor? The frequency measurement in a laser gyro or accelerometer only involves the uncertainty in phase. Therefore, the relevant quantum noise might be reduced by squeezing. Proposals are sought that investigate and utilize squeezing, for example, via the propagation of quantum solitons, for the improvement of inertial sensors.

Proposals should show an understanding of one or more relevant science or exploration needs and present a feasible plan to fully develop a technology and infuse it into a NASA program.

This subtopic is for all mission-enabling GNC technology in support of Science Mission Directorate (SMD) missions and future mission concepts. Proposals for the development of hardware and supporting software is preferred; however, novel algorithms will also be considered. The specific applications could range from CubeSats/SmallSats, to ISS payloads, to flagship missions. For proposals featuring technologies intended for use in planetary science applications, this year a preference will be given to those proposals that would benefit radiation-hard electronics needed for in situ studies of icy ocean worlds.

Expected TRL or TRL Range at completion of the Project: 4 to 6

Primary Technology Taxonomy:
Level 1: TX 17 Guidance, Navigation, and Control (GN&C)
Level 2: TX 17.X Other Guidance, Navigation, and Control

Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software

Desired Deliverables Description:
Prototype hardware/software, documented evidence of delivered TRL (test report, data, etc.), summary analysis, supporting documentation:

- Phase I research should be conducted to demonstrate technical feasibility as well as show a plan towards Phase II integration and component/prototype testing in a relevant environment as described in a final report.
- Phase II technology development efforts shall deliver a component/prototype at the NASA SBIR/STTR TRL 5 to 6 level. Delivery of final documentation, test plans, and test results are required. Delivery of a hardware component/prototype under the Phase II contract is preferred.

Phase I research should be conducted to demonstrate technical feasibility as well as show a plan towards Phase II integration and component/prototype testing in a relevant environment. Phase II technology development efforts shall deliver component/prototype at the Technology Readiness Level (TRL) 5 to 6, consistent with NASA SBIR/STTR descriptions. Delivery of final documentation, test plans, and test results are required. Delivery of a hardware component/prototype under the Phase II contract is preferred.

State of the Art and Critical Gaps:
Capability area gaps:

- **Spacecraft GNC sensors**—highly integrated, low-power, low-weight, and radiation-hard component sensor technologies and multifunctional components.
- **Spacecraft GNC estimation and control algorithms**—sensor fusion, autonomous proximity operations algorithm, robust distributed vehicle formation sensing, and control algorithms.

**Relevance / Science Traceability:**

Mission capability requirements in the Science Mission Directorate (SMD) program areas of Heliophysics, Earth Science, Astrophysics, and Planetary Science:

- **Spacecraft GNC sensors**—optical, radio-frequency (RF), inertial, and advanced concepts for onboard sensing of spacecraft attitude and orbit states.
- **Spacecraft GNC estimation and control algorithms**—innovative concepts for onboard algorithms for attitude/orbit determination and control for single spacecraft, spacecraft rendezvous and docking, and spacecraft formations.

**References:**

1. 2020 NASA Technology Taxonomy: [https://go.nasa.gov/3hGhFJf](https://go.nasa.gov/3hGhFJf)
2. 2017 NASA Strategic Technology Investment Plan: [https://go.usa.gov/xU7sE](https://go.usa.gov/xU7sE)

**Scope Title**

Star-Tracker Technologies for CubeSats

**Scope Description:**

CubeSats are increasingly being used to perform remote sensing of the Earth’s atmosphere and surface. However, their mass, size, and power limitations often prohibit the use of spinning or scanning antennas, especially if such antennas are large relative to the size of the spacecraft (e.g., deployable antennas). A solution is to spin the spacecraft itself; however, spacecraft attitude control and Earth-based geolocation of measurements in this situation requires the use of an onboard star tracker that itself spins or otherwise maintains a consistent frame of reference, or can process star observations quickly enough to update attitude information about the spinning CubeSat. Thus, star trackers capable of providing accurate attitude information to a rapidly spinning CubeSat would significantly benefit future NASA Earth Science CubeSat missions.

The scope of this subtopic is the development of a CubeSat-ready star tracker that can provide accurate attitude information to a rapidly spinning CubeSat hosting an Earth-observing instrument. A CubeSat-ready star tracker that itself spins or maintains a consistent frame of reference while its host CubeSat spins, or one that can process observations significantly faster than the current state of the art (SOA), is a critical enabling technology for CubeSat-based Earth observations that normally would require a spinning antenna (e.g., ocean winds).

**Expected TRL or TRL Range at completion of the Project:** 2 to 6
Primary Technology Taxonomy:
Level 1: TX 17 Guidance, Navigation, and Control (GN&C)
Level 2: TX 17.4 Attitude Estimation Technologies

Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware

Desired Deliverables Description:

Phase I research should be conducted to demonstrate technical feasibility as well as show a plan towards Phase II to include a laboratory-tested to space-qualified hardware prototype of a star tracker capable of providing accurate attitude information to a rapidly spinning CubeSat (~tens of revolutions per minute).

State of the Art and Critical Gaps:

Current CubeSat-ready star trackers can provide ~0.002° pointing information accuracy with low size, weight, and power (SWaP). However, that performance assumes relatively stable attitude control (i.e., a nonrapidly spinning CubeSat). Thus, a CubeSat-ready star tracker that itself spins, or maintains a consistent frame of reference while its host CubeSat spins, or can process observations significantly faster than the current state of the art (SOA), is a critical enabling technology for CubeSat-based Earth observations that normally would require a spinning antenna (e.g., ocean winds).

Relevance / Science Traceability:

Requirement: The star tracker should have the ability to provide 0.05° or better pointing angle accuracy (in roll, pitch, and yaw) while the CubeSat is spinning up to 20 rpm in Low Earth Orbit (300 to 1,000 km altitude).

Relevant CubeSats are anticipated to be oriented such that the Earth-observing antenna is pointing off-nadir by up to 40° to 50°. This provides a sufficient Earth-incidence angle to enable retrieval of ocean surface winds and other horizontally resolved atmospheric measurables (e.g., precipitation). For this science application, the star tracker is providing ~1-km geolocation accuracy for such measurements.

SWaP should be comparable to existing star trackers (~0.2U, ~0.25 kg, ~1 W).

References:

