NASA SBIR 2021 Phase I Solicitation

Z8.11 Artificial Intelligence (AI)/Machine Learning (ML) for Small Spacecraft Swarm Trajectory Control

Lead Center: ARC

Participating Center(s): GSFC, JPL

Scope Title:

Artificial Intelligence (AI)/Machine Learning (ML) for Small Spacecraft Swarm Trajectory Control

Scope Description:

Constellations of small spacecraft currently provide unprecedented persistent coverage of the Earth’s surface, but the use of distributed missions for exploration infrastructure and multipoint scientific measurements beyond Earth will require new approaches to operational efficiency. Current commercial constellations use ground-based semiautonomous scheduling and orbital maintenance to decrease the need for spacecraft-by-spacecraft human-in-the-loop decision making. However, each spacecraft is still individually commanded by the ground-based system. For missions operating beyond Earth, the spacecraft will need to be operated as a single unit. Enabling command and control capabilities within the flight element of the distributed mission will allow control of an otherwise impractical number of small spacecraft as well as decreased operational costs for missions with fewer spacecraft.

NASA intends to expand the exploitation of small spacecraft swarms (or potentially constellations) in support of exploration and science missions. Multiple numbers of SmallSats, working in concert, offer unique capabilities and benefits to space researchers and satellite operators. For instance, some of these advantages embedded in fractionized architectures, such as fault-tolerance and continuous repair and upgrades enabling dynamic, agile, adaptable mission plans, are better able to deal with the unplanned and unexpected. However, as the number of spacecraft grows, and destinations of interest move farther away from traditional low Earth orbit (LEO) orbits, operational challenges created by managing large numbers of agents along with significant space-to-ground communication latencies and bandwidth issues require alternative architectures that are able to make time-critical decisions and operate within the maneuvering limitations of each swarm member. Innovative technologies such as AI/ML can contribute significantly to the success of these deep space, multi-spacecraft missions by providing local control less reliant on the ground, as well as optimal use of propulsion.

Small spacecraft operating in formation, in close proximity to other objects, or beyond the capacity of human-in-the-loop control will be required to process input onboard and execute correct responses autonomously. These sensor-driven operations will be enabling for safe proximity operations with spacecraft or small bodies as well as the detection and reaction to transient events for observation.
This subtopic is interested in software agents and architectures that enable relative stationkeeping, multi-spacecraft orbit determination and prediction, autonomous reactive operations, and interspacecraft timing and communications to enable the above. Proposals should address software applications and/or network applications that enable:

- Efficient information exchange between individual spacecraft.
- Minimal reliance on ground commanding.
- Efficient use of space-qualified computing architectures.
- High-precision swarm navigation and control.
- Asymmetric use of ground assets (emphasizing space side over ground side).

**Expected TRL or TRL Range at completion of the Project:** 3 to 5

**Primary Technology Taxonomy:**
Level 1: TX 10 Autonomous Systems
Level 2: TX 10.2 Reasoning and Acting

**Desired Deliverables of Phase I and Phase II:**

- Software
- Prototype

**Desired Deliverables Description:**

**Phase I Deliverables:**

1. Software architecture design, including figures of merit (FOMs) for performance.
2. Test-bed environment for software development and testing (identify requirements or develop/describe test bed).
3. Plan to continue through Phase II.
4. Phase I report.

**Phase II Deliverables:**

1. Software suitable for testing on test-bed environment.
2. Software description/documentation.
3. Final report, including test results.

**State of the Art and Critical Gaps:**

Currently, the operation of each small spacecraft is individually planned, scheduled, and commanded. Signals from each individual small spacecraft are acquired by ground stations individually. Volumes of unprocessed raw data demand high bandwidth, and this becomes even less practical for greater numbers of cooperative small spacecraft operating at farther distances. As SmallSats are deployed to the Moon, Mars, near-Earth objects (NEOs), and other distant locations, it is costly—in terms of antenna time and human labor—and impractical due to time-of-flight delays at long distance and the fast dynamics of formation flight and cooperative operations to command and control each spacecraft individually, to react to dynamic situations at very remote destinations, and to change the focus of observations, data acquisition, and sample manipulation as areas of interest are discovered at the target. Very little has been done with true swarms of SmallSats, especially in deep space or even lunar locales. Flight processors are becoming more capable, but advanced software, autonomous processes, and adaptive systems that take advantage of increased processing power for SmallSats lag behind. Intelligent, adaptive behaviors and autonomous decision making in reaction to changing conditions at the target, with minimal dependence on Earthbound operators, is needed.

**Relevance / Science Traceability:**
The Small Spacecraft Technology Program is very interested in developing and demonstrating this technology for a broad list of crosscutting applications within the Science Mission Directorate (SMD) and Human Exploration and Operations Mission Directorate (HEOMD). Examples include:

- Fault-tolerant swarms composed of individual assets capable of reassigning their function to compensate for loss of an individual spacecraft.
- Spacecraft capable of decisions and tactical adaptation for acquiring, preprocessing, and transmitting scientific information (rather than raw data) at distant science or exploration destinations.
- Cooperative groups of spacecraft capable of disaggregated inspection, repair, resource resupply, and other functions autonomously and cooperatively at cislunar or more remote destinations.

Small spacecraft conducting science will need to make observations, process dynamic conditions, make decisions, and adapt their performance without manual intervention (for example, sampling the eruption of a plume at Enceladus).

Suggested use cases:

- Investigation of near-Earth asteroids (NEAs) – Orbit determination and maneuvering around an asteroid.
- Coordinated sensor operations (remote sensing, etc.) between multiple spacecraft at planetary destinations.
- Coordinated observation of distant objects (stars, planets) using multiple sensor platforms.
- Autonomous formation flying and inspection of other space assets.

References:

Achieving Science with CubeSats: Thinking Inside the Box. Committee on Achieving Science Goals with CubeSats; Space Studies Board; Division on Engineering and Physical Sciences; National Academies of Sciences, Engineering, and Medicine, 2016. Committee Chair: Thomas Zurbuchen. (https://doi.org/10.17226/23503)


Operating Multiple Satellites as a Single Entity: Introducing SODA. (https://digitalcommons.usu.edu/smallsat/2017/all2017/100/)