NASA STTR 2022 Phase I Solicitation

T10.03  Coordination and Control of Swarms of Space Vehicles

Lead Center: JPL

Participating Center(s): ARC, LaRC

Scope Title

Enabling Technologies for Swarm of Space Vehicles

Scope Description:

This subtopic is focused on developing and demonstrating technologies that enable cooperative operation of swarms of space vehicles in a realistic dynamic environment with limited and realistic communications. Primary interest is in technologies appropriate for low-cardinality (4- to 15-vehicle) swarms of small spacecraft, planetary rovers, and flyers (e.g., Mars helicopter), and underwater vehicles (e.g., Ocean Worlds explorers of the future). Large swarms and other platforms are of interest if well motivated in connection to NASA’s Strategic Plan and needs identified in decadal surveys.

The proposed technology must be motivated by a well-defined design reference mission (DRM) presented in the proposal with clear connection to the needs identified in decadal surveys. The proposed DRM is used to derive the high-level requirements for the technology development effort. Examples of such DRMs can be found in the NASA Science Mission Directorate Autonomy workshop.

Areas of high interest are:

- Distributed estimation for exploration and inspection of a target object or phenomena by various assets with heterogeneous sensors and from various vantage points.
- High-precision relative localization and time synchronization in orbit and on the planet's surface.
- Operations concepts and tools that provide situational awareness and commanding capability for a team of spacecraft or swarm of robots on another planet.
- Coordinated task recognition and planning, operation, and execution with realistic communication limitations.

The proposed technology (hardware and software) should be modular with well-defined interfaces that can be integrated in a variety of missions. Simulation software and general control architectures and technology outside of the areas of interest, identified above, are out of scope for this call.
NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: https://www.nasa.gov/content/commercial-lunar-payload-services. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin soon, and flight opportunities are expected to continue well into the future. In future years, it is expected that larger and more complex payloads will be accommodated. Selection for an award under this solicitation will not guarantee selection for a lunar flight opportunity.

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

**Primary Technology Taxonomy:**
- Level 1: TX 10 Autonomous Systems
- Level 2: TX 10.3 Collaboration and Interaction

**Desired Deliverables of Phase I and Phase II:**
- Research
- Software
- Prototype

**Desired Deliverables Description:**
Phase I awards will be expected to develop theoretical frameworks, algorithms, and software simulation and to demonstrate feasibility (TRL 3). Phase II awards will be expected to demonstrate capability on a hardware or hardware-in-the-loop (HIL) testbed (TRL 4 to 6).

- Phase I and Phase II: Algorithms and research results clearly depicting metrics and performance of the developed technology in comparison to state of the art (SOA). **Software implementation of the developed solution along with simulation platform must be included as a deliverable.**
- Phase II only: Prototype of the sensor or similar if the proposal is to develop such subsystem as a Phase II deliverable.

**State of the Art and Critical Gaps:**
Technologies developed under this subtopic enable and are critical for multi-robot missions for collaborative planetary exploration. Distributed task recognition, allocation, and execution, collaborative motion planning for larger science return, and distributed estimation and shared common operational picture are examples of technology needs in this area. We are interested in technologies that are robust under realistic space environment communication limitations, frequency, and dropouts.

These technologies also enable successful formation flying spacecraft missions, robust distributed guidance, navigation, and control (GNC), precision relative navigation, distributed tasking and execution, and distributed estimation of the swarm state as well as the science target are examples of the technology gaps in this area.

**Relevance / Science Traceability:**
Subtopic technology directly supports NASA Space Technology Roadmap TA4 (4.5.4 Multi-Agent Coordination, 4.2.7 Collaborative Mobility, and 4.3.5 Collaborative Manipulation) and Strategic Space Technology Investment Plan (Robotic and Autonomous Systems: Relative GNC and Supervisory control of an S/C team). SMD's 2018 Workshop on Autonomy for Future NASA Science Missions [17] has identified a number of DRMs with science enabling multi-spacecraft systems.

In addition, the technology developed is also relevant to the following concepts:

- **Cooperative Autonomous Distributed Robotic Explorers (CADRE)** is a STMD-funded lunar multi-agent autonomy technology demonstration where a group of robots collaboratively explore the lunar surface. This promises a low-cost swarm of networked robots that can collaboratively explore lava tubes and other hard-to-reach areas on planet surfaces.
- **Distributed Spacecraft Autonomy** is a technology demonstration mission to show multiple spacecraft can be autonomously tasked and execute decentralized measurement of scientific data.
- **Multi-robot follow-on to the Mars 2020 and Mars helicopter programs** are likely to necessitate close collaboration among flying robots as advanced scouts and rovers.
- **A convoy of spacecraft is being considered in which the lead spacecraft triggers detailed measurement of a very dynamic event by the following spacecraft.**
- **Multiple concepts for distributed space telescopes and distributed synthetic apertures** are proposed that rely heavily on coordination and control technologies developed under this subtopic.

**References:**

14. Decadal Survey for Earth Science and Applications from Space 2018,
    Consistency Planning for Distributed Space Systems," Proceedings of 35th Annual Small Satellite
    Symposium, 2021.
    Swarm Technology Demonstration,” 2018.
17. F. Tan and M. Seablom, 2018 Workshop on Autonomy for Future NASA Science Missions: Output and