SBIR/STTR
Small Business Innovation Research / Small Business Technology Transfer

NASA SBIR 2020 Phase I Solicitation

Z3.04 Autonomous Modular Assembly Technology for OSAM

Lead Center: LaRC

Participating Center(s): MSFC

Technology Area: TA4 Robotics, Telerobotics and Autonomous Systems

Scope Title

Autonomous Modular Assembly Technology for On-Orbit Servicing, Assembly and Manufacturing (OSAM)

Scope Description

As NASA seeks to extend its presence into deep space, ground-based human intelligence applied to supervision, control, and intervention of operations will no longer be viable due to system and mission complexity and communication delays. Therefore, trusted and certified-safe autonomous systems with machine intelligence and robotic capabilities of responding to both nominal and unexpected situations will be needed. These systems should be capable of:

- Sensing and perception
- Acquiring measurements on-orbit or on planetary surfaces
- Achieving situational awareness
- Making decisions
- Taking action
- Teaming with humans and other machine agents
- Using experiential data to update capabilities
- Verifying autonomy algorithms and behavior
- Validating as-assembled structure shape and interface integrity

As such, autonomy, system modularity, metrology, and modeling & simulation are four critical aspects required to enable On-Orbit Servicing, Assembly, and Manufacturing (OSAM). The hardware and software components of an in-space assembled structure must be modular to facilitate servicing, component replacement, and reconfiguration of the spacecraft. Assembly by autonomous robots can reduce the workload on astronauts and ground crew as well as mitigate inefficiencies due to communication delays associated with teleoperation. The OSAM paradigm requires multiple autonomous agents to collaborate in a complex, dynamic environment. These agents will need to accurately perceive both their environment (the worksite) and each other in order to efficiently allocate tasks, plan trajectories, and respond to disturbances all in the presence of uncertainties such as unknown payload characteristics and unmodeled effects.

Modular structures will increase ease of access to space. Modular platforms could host flight hardware and share power, data, Guidance, Navigation and Control (GN&C), and thermal regulation capabilities. Under this paradigm, technology demonstrations could be carried out without the need to design and operate an entire spacecraft. Modules could simply occupy space on the already existing platform. This constitutes a plug-and-play architecture which will require a common interface between modules such that required structural loads can be supported as well as power, data, and other services.

Modeling & simulation of structures and assembly agents is necessary for verifying autonomous agent algorithms and behavior used for structures that cannot be assembled on the ground.

Accurate sensing of complex and uncertain environments is necessary to provide autonomous agents with situational awareness to accomplish assembly tasks. Validation of the autonomous system behavior and in-space assembled structure accuracy in-situ will require in-space metrology capabilities.

The scope of this subtopic includes modular hardware and software systems:

- ***Element 1*: Algorithms and software for sensing, planning and control of both autonomous robots and mission/task management agents
- ***Element 2*: Novel hardware designs (modular robots and structures)
- ***Element 3*: Hardware and software for global (worksite scale) metrology systems for accurately sensing agent and structure pose within an on-orbit or lunar assembly worksite
- ***Element 4*: Novel approaches to dynamics-based mathematical modeling for complex rigid-body connections and independent verification and validation for dynamics-based rigid multi-body mathematical models

Specific subjects to be considered include

- ***Heterogeneous multi-agent planning and control*: Algorithms for collaboration on shared tasks for assembly of large modular space structures; task allocation amongst multiple agents; trajectory planning through the worksite and real-time updating of tasks and trajectories to respond to unplanned scenarios; robust and adaptive control for guaranteed performance or graceful degradation of performance for robotic manipulators and/or novel assembly agents; teaming of humans and machines for planning, validation, and post-assembly analysis
- ***Strategies and solutions for error detection and correction during the assembly process*: Perception systems and/or classification algorithms independent from the assembly agent for verifying assembly steps and characterizing assembly errors. Fault/anomaly detection, diagnosis, and response to restore nominal operations or derive an acceptable alternative goal
- ***Metrology systems*: Global metrology systems or sensing tools that can map a worksite to facilitate agent and structure assembly path-planning for real-time task management and situational awareness and facilitate verification and validation of assembly tasks. A scalable system that can accurately measure structures at an in-space (orbital or surface) worksite with a focus on minimal supporting infrastructure is desired. Concepts with potential for integration and repurposing after construction are favored.
- ***Modular structures, systems, and tools*: Deployables that are rigidizable by an accompanying in-situ system (i.e. trusses or functional modules), can be serviced (due to modularity), are capable of moving along truss structures of variable geometries, and/or can interface with agents or be stored/stowed at a worksite where the agent mostly acts as a driver for a mobility system. Of particular interest are approaches to efficiently connect truss modules together. Hardware concepts that support the interconnection of modules in the 100 â€“ 5,000 kg range using some form of space robotics. The objective is to minimize the parasitic mass of the completed spacecraft from the modularity features that are required for inter-module assembly. Features can be added and removed to reduce this parasitic mass. Proposals are preferred that include features to connect both electrical (power and data) and structural features, noting that the connections can occur sequentially. Joining strategies that support fluid connections are of interest but not necessary to be responsive to this subtopic area. The structural connection should occur at a minimum of 3 discrete locations fixing the rigid body motion of the 2 modules in all 6 degrees of freedom while isolating (minimizing) forces resulting from thermal induced strain between the modules consistent with a LEO orbit. The three (or more) connections do not have to occur simultaneously.
- ***Modeling & simulation*: Novel approaches to dynamics-based mathematical modeling for complex rigid-body connections with nonlinear effects (for example, slider, ball, or slot connections) and independent

verification and validation for dynamics-based rigid multi-body mathematical models. Of particular interest are accurate dynamics-based models for joining of modules on-orbit or in planetary environments.

References

- NASA in-Space Assembled Telescope (iSAT) Study: https://exoplanets.nasa.gov/exep/technology/in-space-assembly/iSAT_study/
- NASA Raven: https://www.nasa.gov/mission_pages/station/research/experiments/explorer/Investigation.html?#id=1734
- NASA Robotic Refueling Mission (RRM3): https://sspd.gsfc.nasa.gov/RRM3.html
- NASA Restore-L: https://sspd.gsfc.nasa.gov/restore-L.html
- NASA Dragonfly: https://www.nasa.gov/mission_pages/tdm/irma/nasas-dragonfly-project-demonstrates-robotic-satellite-assembly-critical-to-future-space.html
- Autonomous Systems NASA Capability Overview: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180007804.pdf

Expected TRL or TRL range at completion of the project: 3 to 5

Desired Deliverables of Phase II

Hardware, Software

Desired Deliverables Description

- Software implementations and documentation verifying the efficacy of the designed algorithms
- Physical prototypes and documentation for the designed hardware

State of the Art and Critical Gaps

As humans venture into deeper space, communication latency will increase to the point that autonomous operations are crucial. Current technologies for autonomous robots are low TRL, application specific, and fragile with respect to environmental uncertainties. To enable OSAM, these technologies must be made more resilient. Many interesting ideas exist in academia, but have yet to be made into a viable product.

Existing interfaces for modular trusses are purely structural. A critical gap is the development of interfaces that can exchange power, data, and other services over the interface.

Relevance / Science Traceability

Achieving a robust and resilient autonomous solution for OSAM requires the intersection of many disciplines including mechanical and electrical systems, robotics, dynamics modeling, control theory, and computer science. NASA goals that would directly benefit from this work are future lunar exploration missions, including sustained human presence on the moon and persistent space platforms.