NASA SBIR 2016 Phase I Solicitation

H6   Autonomous and Robotic Systems

NASA invests in the development of autonomous systems, advanced avionics, and robotics technology capabilities for the purpose of enabling complex missions and technology demonstrations supporting the Human Exploration and Operations Mission Directorate (HEOMD). The software, avionics, and robotics elements requested within this topic are critical to enhancing human spaceflight system functionality. These elements increase autonomy and system reliability; reduce system vulnerability to extreme radiation and thermal environments; and support human exploration missions with robotic assistants, precursors and caretaker robots. As key and enabling technology areas, autonomous systems, avionics and robotics are applicable to broad areas of technology use, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable complex or long duration space missions. All of these flight applications will require unique advances in autonomy, software, robotic technologies and avionics. The exploration of space requires the best of the nation's technical community to provide the technologies, engineering, and systems to enable human exploration beyond LEO, to visit Asteroids and the Moon, and to extend our reach to Mars.

NASA is investing in technologies and techniques geared towards advancing the state of the art of spacecraft systems through the utilization of the ISS as a technology test bed. For technologies that could benefit from demonstration on ISS, proposals should be written to indicate the intent to utilize ISS. Research should be conducted to demonstrate technical feasibility and prototype hardware development during Phase I and show a path toward Phase II hardware and software demonstration and delivering an engineering development unit or software package for NASA testing at the completion of the Phase II contract that could be turned into a proof-of-concept system which can be demonstrated in flight.

Subtopics

H6.01 Robotic Systems - Mobility, Manipulation, and Human-System Interaction

Lead Center: JSC

Participating Center(s): ARC, JPL, KSC

The objective of this subtopic is to create autonomous systems and robotic technologies (hardware and software) to improve the human exploration of space. Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans. Ground controllers and astronauts will remotely operate robots using a range of control modes (tele-operation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, on orbit, and interplanetary), and with a range of time-delay and communications bandwidth. Additionally, in order to build robotic systems that are cheaper, lighter, and more energy efficient than traditional devices based only on rigid assemblies, it is important to develop soft robotics technology for mobility and manipulation.

The software, avionics, and robotics elements requested within this topic are critical to increasing autonomy and system reliability; reducing system vulnerability to extreme radiation and thermal environments; and supporting human exploration missions with robotic assistants, precursors and caretaker robots. As key and enabling technology areas, autonomous systems, avionics, and soft robotics technologies are applicable to broad areas of technology use, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable complex or long duration space missions. All of these flight applications will require unique advances in autonomy, software, robotic technologies and avionics. The exploration of space requires the best of the nation's technical community to provide the technologies, engineering, and systems to enable human exploration beyond LEO, to visit Asteroids and the Moon, and to extend our reach to Mars.Â

Proposals are sought to research and develop the following:

- *Mobility* - Subsystems to improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, and in-space. This includes: hazard detection sensors/perception; active suspension; grappling/anchoring; legged locomotion; robot navigation; infrastructure-free localization and sensors for deformable, flexible or active elastic mobility components.
- *Manipulation* - Subsystems to improve handling and maintenance of payloads and assets. This includes: tactile sensors; human-safe actuation active structures; dexterous grasping; modular â€œplug and playâ€ mechanisms for deployment and setup; small/lightweight excavation devices; novel manipulation methods; and actuators and/or sensors for active tension control (including tendon-based manipulation and dynamic tensegrity).
- *Human-system interaction* - Subsystems that enable crew and ground controllers to better operate, monitor and supervise robots. This includes: robot user interfaces; automated performance monitoring; tactical planning software; real-time visualization/notification; software for situational awareness and modeling/simulation software for soft robotics (including design of highly compliant and/or underactuated dynamic systems).

H6.02 Requirements Management for Spacecraft Autonomy and Space Mission Automation

Lead Center: ARC

System and software requirements for autonomy have been difficult to define and test due to uncertainties in the environment in which autonomous systems might be deployed, the flexible yet safe interaction with in-situ humans that is needed, and the adaptability needed from an autonomous system for novel situations. Future human spaceflight missions will place crews and other assets at large distances and light-time delays from Earth that will need to act autonomously from mission control over significant time intervals in both nominal and emergency situations. Space missions have small crew sizes, and many mission concepts involve spacecraft and habitats that are only intermittently crewed, so automation through software will be a major portion of autonomous systems.Â

Proposals are solicited that provide novel methods and tools specifically targeted to defining and testing requirements for autonomy capabilities, including the definition of interactions and roles with in-situ humans. Proposals should encompass a subset of the following: methods and tools for autonomy requirement definition, refinement, verification of internal consistency, validation, and testing during subsequent development.Â

Proposals should compare their proposed methods and tools to conventional requirements management, and indicate why their methods and tools will result in requirements for autonomy with less ambiguity,Â fewer conflicts between different requirements, and more testable requirements - as compared toÂ state of the art requirements methods. Proposals should provide metrics for measuring the quality of autonomy requirements resulting from their methods and tools compared to SOA. For example, in the aircraft industry today over half of system development errors originate during the requirements phase, while over 75%Â of system development errors are caught very late in development - typically in late phases of testing. This leads to high costs and development schedule overruns due to rework. Proposers should ground their proposed research by demonstrating methods and tools on plausible design reference missions involving autonomy.Â

Proposals should indicate how their methods and tools will bridge the gap between requirements definition and

requirements-based testing, potentially including semi-automatic test generation suitable for the autonomy attributes of flexible response in uncertain environments with uncertain situations. Â

Proposals can draw upon a wide range of methods, including but not limited to ontology definition, uncertainty quantification, formal approaches to requirements engineering, Â symbolic methods Â for test generation from requirements, and techniques for requirements elicitation from stakeholders. Proposals that involve natural language as a medium for autonomy system and software requirements definition should describe how the natural language will be disambiguated in subsequent phases of system development.

H6.03 Spacecraft Autonomy and Space Mission Automation for Consumables

Lead Center: ARC

Participating Center(s): JPL, JSC

Future human spaceflight missions will place crewâ€™s at large distances and light-time delays from Earth, requiring novel capabilities for crews and ground to manage spacecraft consumables and renewables such as power, water, propellant and life support systems to prevent Loss of Mission (LOM) or Loss of Crew (LOC). Â This capability is necessary to reconfigure spacecraft, or replan missions, Â in response to Â events such as leaks or failures leading to unexpected expenditure of consumables coupled with lack of communications. If crews in the spacecraft must manage, plan and operate much of the mission themselves, NASA must migrate operations functionality from the flight control room to the vehicle for use by the crew. Migrating flight controller tools and procedures to the crew on-board the spacecraft would, even if technically possible, overburden the crew. Enabling these same monitoring, tracking, and management capabilities on-board the spacecraft for a small crew to use will require significant automation and decision support software. Â Required capabilities to enable future human spaceflight to distant destinations include:

- Enable on-board crew management of vehicle consumables that are currently flight controller responsibilities. Â
- Increase the onboard capability to detect and respond to unexpected consumables-management related events and faults without dependence on ground.
- Reduce up-front and recurring software costs to produce flight-critical software.
- Provide more efficient and cost effective ground based operations through automation of consumables management processes, and up-front and recurring mission operations software costs.

Necessary capabilities include:

- Peer-to-peer mission operations planning.
- Mixed initiative planning systems.
- Elicitation of mission planning constraints and preferences.
- Planning system software integration.
- Space Vehicle System Â Automation.
- Autonomous rendezvous and docking software.
- Integrated discrete and continuous control software.
- Long-duration high-reliability autonomous system.
- Power aware computing.
- Power Systems Autonomous Control.
- Vehicle Systems Automation.
- Crew Situational Awareness of Vehicle Automation.
- Contingency Management.

The emphasis of proposed efforts should focus primarily on software systems, but emphasize hardware and operating systems the proposed software will run on (e.g., processors, sensors), and proposals must demonstrate understanding of the consumables and dependent spacecraft systems that the software is intended to manage. Â

Proposals may reference existing fault management techniques, but this subtopic does not solicit development of fault management capability; proposers interested in developing these capabilities are referred to the relevant H6

topic area (H6.04). Â While Verification, Validation and Requirements of autonomous systems is also an important area, this subtopic does not solicit development of these technologies, Â proposers interested in developing these capabilities are referred to the relevant H6 topic area (H6.02).

Proposals must demonstrate mission operations cost reduction by use of standards, open source software, crew workload reduction, and/or decrease of software integration costs.

Proposals must demonstrate autonomy software cost reduction by use of standards, demonstration of capability especially on long-duration missions, system integration, and/or open source software.

H6.04 Integrating ISHM with Flight Avionics Architectures for Cyber-Physical Space Systems

Lead Center: ARC

This call for SBIR proposals is for technology development of integrated flight control systems for seamless integration of flight avionics with Integrated Systems Health Management (ISHM) systems. Flight avionics, with Integrated Modular Avionics (IMA) have well-defined Caution and Warning (CW) Fault Detection Isolation and Response (FDIR) alerting systems which in can in real-time detect, isolate and respond to single failures at a time. Â For each CW failure, a predefined mapping to a CW response procedure is defined. In this way when real time conditions occur, response can be almost immediate. However this approach suffers when more than one failure is present. Under multiple CW failures more than one CW response procedure is active. Which of the predefined procedures should you execute? A procedure execution deadlock can occur. Currently when procedure deadlock occurs a number of questions need to be addressed by flight/ground:

- At what step in each procedure should you execute first?
- Should procedure steps be removed /added?
- Should procedure steps be interleaved between procedures?
- Should an entirely new procedure by synthesized?

The determination of how to proceed from procedure deadlock under multiple failure scenarios is critically dependent upon the correct multiple failure diagnosis of the situation. ISHM supports this determination due to the fact that ISHM can extend traditional CW FDIR systems to utilize a systems view of the spacecraft which leverages all (or most) of the available sensors and command talk-back information. Whereas traditional CW FDIR logic are often small fragments of logic and code which utilize subsets of the sensors, and in general Â have no knowledge and/or context of the other FDIR algorithms, a global view allows for a global response Â but also brings additional challenges of determining that the data from all the sensors is consistent. It is also important to recognize that failure signatures/ propagation/fault masking can be the result of not only hardware but also the interaction of the myriad control loops and procedural behavior that is induced by the flight avionics. Another key aspect is to perform interpretation of fault data in the context of mission operations, and subsequent fault recovery consistent with current mission goals. Additional challenges are also to devise methods to automatically develop the ISHM fault models from system descriptions such as the schematics, procedures, etc.

To date however seamless integration of ISHM systems with flight avionics CW FDIR systems has not matured to the level such that ISHM systems are trusted to support flight avionics systems in multiple failure high stress situations such as CW storms. Prior human-rated approaches have been proposed but not baselined for similar functional situations in both the Space Shuttle domain (Enhanced Caution and Warning (ECW) as part of the Cockpit Avionics Upgrade (CAU) program) as well as the International Space Station domain (ISS 24-hour autonomy mode). Â The challenge is to extend the lessons learned from these efforts to achieve program insertion. Such efforts will support both crewed as well as robotic missions, both near Earth as well as deep space missions. Support will be enabled under a variety of conditions including where:

- Communication time with Earth is insufficient and/or delayed.
- Communication bandwidth is insufficient.
- The complexity of analysis is beyond human comprehension.
- The reliance on a skeleton crew requires additional computational support.

Seamless integration can be defined through many dimensions. Several dimensions of interest are:Â

- Allow the operator the ability to select between a palette of ISHM modules.
- Allow the operator the ability to turn on/off the ISHM module.
- Real time support for flight avionics. At least one scenario should be defined which shows the operation of the flight avionics with and without ISHM.

In order to demonstrate a technology solution, proposed work should include as baseline, aÂ representative set of hypothetical CW events, a FDIR procedure response for each CW event, and one or more scenarios where, with multiple CW events across subsystems, the set of applicable FDIR procedures deadlocks. The proposed work should then demonstrate how the procedure deadlock is resolved through the proposed technology solution which integrates ISHM with the flight avionics.