NASA SBIR 2004 Phase I Solicitation

X7 Information and Communication

This topic covers information and communications technologies essential to the manned and unmanned exploration of Cis-Lunar, Lunar, Cis-Martian space and beyond. Exploration to Mars and the outer planets will be conducted in a “staged” approach in which unmanned and manned missions to the Moon, and Mars will be used as proving grounds, as well as destinations on the path to the next objective. To accomplish this effort, advanced systems including manned and unmanned spacecraft, space stations, lunar and Martian surface facilities, as well as a combination of robotic explorers and human exploration crews will be employed. It is essential that interoperable communication and knowledge transfer exist between each class of system. Specific areas of interest include RF and laser-based telecommunication systems, intelligent onboard systems, and mission training systems. Technologies are being sought to provide communication hardware, data links, high data rate, teleoperation, knowledge transfer, data fusion, simulation modeling, sensory immersion, and human and machine interfaces to allow sustained human presence beyond low-Earth orbit. Innovations are sought at the component and subsystem level and include software, electronics, materials, and manufacturing processes.

Subtopics

X7.01 Radio Frequency (RF) Telecommunications Systems

Lead Center: GSFC
Participating Center(s): GRC

The intent of this subtopic is to seek innovations in RF telecommunications systems in support of the Exploration Systems Enterprise plan for manned and unmanned exploration beyond Earth orbit, resulting in a permanent human presence throughout the Solar System. NASA envisions a future including manned and robotic missions to the Moon, Mars, the asteroid belt, and beyond.

These missions require both long-range data links of hundreds of megabits per second, as well as short range (surface-to-surface and surface-to-orbit) data links between power-limited systems including rovers and personal radios. Current systems do not support the high data rates, low power, and low mass required by large numbers of robotic and manned explorers. Near term efforts should focus on the needs of robotic and Cis-Lunar operations. Specific areas of interest include wireless communication crosslinks between robotic rovers, teleoperation of robotic explorers on the lunar surface, communication links between the lunar surface and lunar orbit, and high bandwidth, direct surface-to-Earth links.
Specific areas of research include, but are not limited to the following:

**Fault Tolerant Digital Signal Processing (DSP)**

DSP and software defined radio techniques provide tremendous flexibility and power to a communication system. To fully realize the benefits of SDR and DSP, powerful, reconfigurable systems are required using a combination of FPGA and general purpose processors. Current space-qualified DSP elements do not support high bandwidths because of power consumption associated with radiation hardened manufacturing processes, while high bandwidth commercial components cannot survive the space environment.

NASA is interested in the development of a component technology based on commercial DSP and FPGA architectures that provides autonomous fault detection and correction with a graceful degradation in performance over the service life. Single event upsets (SEUs) would be detected and corrected without requiring redundant logic design. Physical “hard” damage due to heavy ionizing radiation would be detected, and affected logic would be re-routed to avoid damaged areas.

Phase I deliverables would include a demonstration to NASA of the technology implemented in commercial components with the prototype delivered to NASA for testing and evaluation. Phase II deliverables would include delivery to NASA of small volume production runs of flight capable components suitable for evaluation, test, and integration into technology demonstration flights.

**High Efficiency Power Amplifiers**

Data links are envisioned from the Moon and Mars in the hundreds of megabits, requiring powerful RF transmitters. With large amounts of power being used for data return, it is essential to provide an efficient conversion to RF. Higher amplifier efficiency translates directly into lower power consumption for a given bandwidth, immediately extending the science-return of a mission.

Amplifiers are needed in the S and Ku bands. Low power amplifiers should be on the order of a few hundred grams, with power levels between 5–10 W, and efficiencies greater than 60%. High power amplifiers should exceed 100 W for SSPA with greater than 60% efficiencies.

Phase I would include the delivery of a prototype system to NASA for evaluation and test. Phase II would include the delivery of a limited production run to NASA for use in laboratory testing and flight demonstrations.

**X7.02 Intelligent Onboard Systems**

Lead Center: ARC
Participating Center(s): GSFC, JSC
The intent of this subtopic is to seek innovative technologies that enable intelligent onboard systems to dramatically increase onboard autonomy. As NASA prepares for future exploration missions, system status and performance capability is required to ensure crew safety and mission. Traditional means of providing this information, such as inspections and preventive maintenance, are an extremely limited utility for exploration missions. Other solutions, such as telemetry data, become less useful as communication bandwidth shrinks and communication delays increase. Under these circumstances, increasing the intelligence of the onboard systems provides the best means of managing onboard system operations. Intelligent onboard system technologies generally involve the use of goal-oriented autonomous operations, requiring means for sensing the environment and making intelligent choices with regard to resources, operations, health and safety, logistics, and configuration. Specific areas of research include the following:

**Intelligent Onboard System Architecture**

Proposals addressing this area may focus on developing innovative methods that integrate the core set of intelligent system elements including system reconfiguration, integrated vehicle health management, planning and execution, and human machine interactions, to ensure the right information is delivered at the right place and time to execute the onboard vehicle system functions throughout all mission phases.

**Reconfigurable Systems**

Proposals addressing this area may focus on developing innovative techniques and strategies for performing system reconfigurations based on Integrated Vehicle Health Management (IVHM) information. System reconfiguration is an important element of system and vehicle management functions. One of the main characteristics of this element is that an intelligent agent will sense and react to the environment by reconfiguring the vehicle systems based on the current situation and resource requirements to maximize operational margins. In addition, the reconfiguration function must take into account the avionics architecture which includes hardware and software cross strapping of systems and data, and redundancy management of the vehicle.

**Integrated Vehicle Health Management (IVHM)**

Proposals addressing this area may focus on developing innovative techniques for performing system health management functions. IVHM holds many promises for future flight improvements. The function is designed to decrease the anomaly response time. Different inference mechanisms may be explored to focus on detecting failures, determining the root cause, and reporting the severity of the failures based on the operating context and priority. Prognostic techniques might also be used to anticipate system degradation, which enables further improvement in mission success probability, operational effectiveness, human-machine teaming, and automated functional restoration.

**Planning and Execution (P&E)**

Proposals addressing this area may focus on developing innovative techniques for performing the P&E functions. The planning function is designed to facilitate the coordination of plans and to resolve conflicts across multiple systems and operational constraints, such as coordinating multiple procedures, flight rules, and malfunctions, to achieve the mission objectives. The execution function is to perform the planned procedures. In order to improve the robustness of the execution function, however, alternatives paths should also be modeled to accommodate the changing environment. For this area of research, the performance and the scope of the P&E function must be evaluated in the context of the future space vehicle operation concepts. The issue related to how much the long-term planning function needs to be modeled onboard should be assessed and traded for the complexity of knowledge capture, verification, and validation costs.
Human/Machine Interface

Proposals addressing this area may focus on developing innovative techniques for performing the human/machine interface functions. The goal of the human/machine interface element is to integrate the human crewmembers into a highly automated onboard system. While most vehicle functions will occur under the control of the automation, the human crew must be able to take control of some or all of the vehicle functions in certain mission phases. Because the vehicle is highly automated, it is anticipated that the crewmembers will allow the onboard vehicle automation to handle most, if not all, of the routine operations. Another important goal of the human/machine interface element is to explore the various techniques for providing situational awareness of the current vehicle state. Using this awareness, the crew must have the ability to safely transition from automated control to manual control during all mission phases. Subsequent manual control must be safe, effective, and efficient.

Operations Knowledge Management

Proposals addressing this area may focus on developing innovative tools, techniques, and representations to capture the corporate knowledge about manned spacecraft operations and to quickly and effectively update, test, and certify the operational knowledge and rule bases. Currently, the space flight operations knowledge is being documented in a variety of different sources. For example, flight rules are used in manned space operations to document policies affecting crew safety, vehicle integrity, and critical capabilities and mission success. These policies describe permitted, prohibited and required actions, mission priorities, and program standards. In order to effectively use this set of information for developing the intelligent onboard system, a knowledge capture system must be developed to assist the capturing of the operational knowledge for both human and automated reasoning systems.

Verification and Validation of the Intelligent Onboard Systems

Proposals addressing this area may focus on developing innovative techniques and tools for verifying and validating the intelligent onboard systems. The verification and validation objective is to allow the engineers who are responsible for developing the onboard system to use the tools routinely during design and development, and also during maintenance operations to check for critical system errors. As the onboard software becomes more complex and increasingly more autonomous, a guarantee of intelligent software and knowledgebase correctness becomes even more important and challenging. Example technologies that might be used for intelligent onboard systems are model-based reasoning, rule based systems, and adaptive learning systems.

Life Support System Intelligence

Proposals addressing this area may focus on developing innovative techniques and approaches for providing life support system intelligence for maintaining biological samples. This also involves continuous monitoring of environmental conditions and life support equipment, reprocessing and filtering of consumables, and autonomous management of the supply, control, and distribution of energy.
X7.03 Mission Training Systems
Lead Center: JSC

The technologies required for this subtopic focus on getting away from large training facilities and to provide the same fidelity of training in virtual environments or small training systems. We are looking for training technologies that will facilitate distributed training across an international community and even to a lunar base. Finally, we are looking for innovations that will enable integrated robotic and human operations training in a virtual environment.

Distributed Training

We are looking for innovations that use, build upon, and innovate on the distributed training technologies of the military High Level Architecture (HLA) and the distributed Web training technologies. These innovations should enable simulation and model interaction across an international community. It should ensure secure model interaction over public networks to facilitate low cost connectivity between the international training facilities. The innovation should ensure low bandwidth “real-time” simulation interaction across an international community. Finally, we are looking for innovations that will stretch the distance of the simulation/model interaction across a lunar distance.

Integrated Human/Robotic Training Systems

Innovations and technologies that will enable integrated training environments for autonomous or semi-autonomous robotic systems with human activities are required. These integrated environments should enable the robotic training systems to be located at one location (e.g., Jet Propulsion Laboratory) and the human training systems to be located at a different location (e.g., Johnson Space Center). The training simulation would be controlled at both locations but the participants and robots in the training session would interact as if they were collocated in the same facility.

Training Systems on the Operational Platform

Weight and space considerations will require us to have the training systems collocated with the operational capabilities of the transportation vehicle or on the lunar base. We are looking for innovations that will provide for isolated simulation systems that are embedded and accessible on the operational platform. These systems must enable the individual to train for a task on the operational system without affecting the performance of the vehicle or facility. These innovations should also enable the ability to use the simulation models as part of the analysis tools that are used to monitor the systems. The models used for the training would provide the predicted behavior of the vehicle and could be tied into an Integrated Vehicle Health Monitoring system that would compare the predicted models with the actual system performance and inform the user of any deviations.

Distributed Virtual Environments

Along with technologies that enable distributed model interaction, we are seeking technologies that will facilitate interactive virtual environments across an international community. These systems should provide realistic sensory feedback including tactical, audible and visual in order to provide the distributed team with the appropriate perception required to complete the task. The feedback should also reflect the realistic sensory feedback in a micro-gravity, 1/6 g or 1 g environment. The virtual environments should provide realistic models of the lunar environment and the objects rendered should be realistic representations of the systems on the space vehicle tied to the distributed models mentioned above. The virtual environments should enable easy reconfiguration of the environment (including the gravity aspects mentioned previously) and should enable the connection with other models including a virtual human for realistic human performance. The training environments should also provide the operations community to interact with the participants in the training. We are looking for environments that not only train the individuals performing a task, but the team that is tasked with monitoring their operations and the
systems being used to enable the task to be performed. At NASA, this team is known as the Control Center Operations team.

**Modular Training Systems**

We are looking for innovations that will enable various models and simulations to be easily plugged into a training environment. Currently, the training systems are so integrated with the simulations that it takes extensive effort to reconfigure the training environment from models from different companies or countries. We are looking for new standard simulation interfaces that will enable this plug-and-play capability. This would also extend to the interface side where it would be easily integrated with a virtual environment, a desktop environment, or an autostereoscopic display.

**Adaptive Training Environments**

We are looking for innovations that will use and build upon the gaming industries ability to automatically reconfigure the simulation based on a student's demonstrated expertise in the simulation. We are looking for this capability applied to operations and tasks associated with a translunar or lunar environment. Also in the joint robotic/human operations, we are looking for systems that will enable the robotic autonomy to be tunable to train varying degrees of human interaction with the robotic systems. Finally, the adaptive training environments should allow the student to determine the depth of training in the virtual environment.

**X7.04 Human Surface Systems Electronics and Communications**

*Lead Center: JSC*

This subtopic focuses on the electronics and communications technologies needed for deploying human expeditions in deep space and on planetary surfaces. The target environment is beyond the protection of the Earth's magnetic field, exposing devices to a high rate of cosmic radiation that induces latch up and single event upset (SEU), but low total dose because excess crew exposure will be avoided. On planetary surfaces, equipment outside habitable areas also sees temperature extremes and physical contaminants. The system architecture will require a larger number of diverse and complex devices, closer in function to commercial devices than is the case with unmanned missions. Minimizing weight and volume are critical requirements for missions into deep space and planetary gravitational wells. This introduction spells out common objectives, while each area description provides a technical objective and specifies the relative emphasis the environment should be given at this time.

The function and use of these systems should be similar to the function and use of automated, semi-automated, and information technology systems otherwise in use near the time in which the exploration mission occurs, but with additional self-monitoring for fault detection and management. Where a system's function is critical it requires fault tolerance and rapid reconfiguration. Unlike the low-Earth orbit environment, commercial components will rarely be usable, and unlike smaller unmanned projects, custom development of a significant percentage of the components will not be feasible.

Specific areas of interest relating to human surface systems for human exploration include the following:
**Integrated Multi-Channel Control Devices**

Human mission support systems tend to require actuators and motor controllers for micro-flyers and teleoperated robots (hand with fingers) that demand high reliability. Temperature range and more particularly, radiation tolerance requirements, must be met. Radiation induced latch-up failure of power devices must be strictly avoided as it creates a high-energy failure that can cascade into other nearby systems.

For actuators, 4–12 channels of 1–4 amperes high side switching of 28 V with back electromotive force (EMF) clamping are desirable. Use of complementary metal oxide semiconductor (CMOS) technology would ease on-chip integration with other functions. Fabrication processes chosen should be affordable for prototyping, as well as modest production runs. Channel fault monitoring should be integrated, along with latch-up prevention, for use in the target environment.

For multi-channel motor controllers, actuator devices should be integrated with radiation tolerant control circuitry, and they should be able to generate optimum sine wave control signals in power circuits using pulse width modulation.

We are primarily interested in components or systems which function in the target environment. Phase I proposals should include prototype hardware demonstrations delivered to NASA for test and evaluation. Phase II proposals should include sample quantities of production quality hardware for evaluation, test and use in-flight experiments.

**Integrated Multi-Channel Data Acquisition Components**

These are devices that provide filtering, amplification, and multiplexing to support the acquisition of low-level signals in a noisy environment with a minimization of wiring and power. Unlike commercial devices, which usually do not provide per-channel filtering for large channel counts, and frequently are implemented with very radiation-susceptible mixed-signal process technologies, the components required for surface exploration systems must be very robust both with respect to noise and radiation.

The purpose is to avoid limiting the number of channels monitored and to always provide sufficient data to determine the health and status of systems and equipment deployed to the surfaces of other planets. Requirements include acquiring data from sensors with low level output, such as strain gauges and thermocouples, easily swamped by noise and filtering.

The desired architecture would allow configurability of gain up to several hundred and filtering down to a few tens of Hertz, with control and output data multiplexed onto a small number of wires or communication channels. Both wired and wireless systems are of interest. Ability to integrate with other functions, such as control and communications, is preferred. Devices should contain calibration and self-test functions.

Phase I proposals should include prototype hardware demonstrations delivered to NASA for test and evaluation. Phase II proposals should include sample quantities of production quality hardware for evaluation, test and use in-flight experiments. Proposals may optionally use patented NASA radiation tolerant technology (US 6,377,097 B1) and patent-pending instrumentation technology for on-chip filters and multi-channel architectures.
Environmentally Rugged and Reliable Versions of Commercial Computer and Communications Devices

This area addresses both complete devices such as laptops and communication handsets, and components such as processors and field programmable gate array's (FPGA's). NASA relies increasingly on complex FPGA devices, which may contain memory, bus interfaces, processors or other complex intellectual property. The environment of deep space and planetary surfaces is more severe; however, it is estimated that the qualification testing approach will not be sufficient.

The diversity of devices needed to support human exploration and the closeness to commercial state-of-the-art which is expected, are not typically addressed when deploying robotic-only missions. The continuously growing complexity and proprietary intellectual property content make it undesirable to completely re-engineer such devices as flat panel displays and their controllers, multigigahertz central processors, and the communication protocols. Cost-effective processes implementing environmentally suitable versions of common commercial computer and communications devices are highly desired.

Methods for cost-effectively producing radiation tolerant and thermally enhanced versions of near state-of-the-art digital, radio frequency (RF), FPGA, display, and user interface components are desired. Issues of design tool affordability, design flow completeness, and viability for low or moderate volume applications should be considered. Note that shielding is generally not adequate mitigation for cosmic radiation.

Phase I should include demonstrations of tool flow and process flow as applicable and an actual demonstration of some aspect of the ruggedization, which can be evaluated and tested by NASA. Phase II should include sample quantities of complete systems or process flows delivered to NASA for use in prototype flight projects. Proposals may optionally use patented NASA radiation tolerant technology (US 6,377,097 B1).

Reconfigurable Software Defined Radio (SDR)

Human planetary surface exploration and deep space missions will deploy a wide variety of vehicles, tools, and experiments that have unique requirements for modulation, data rate, etc. Reconfigurable SDR techniques are desired to minimize the development time and cost for diverse communication systems, as well as the number of separate radios necessary on various spacecraft.

SDR components must be small and low power to broaden their application range. Target applications include such functions as integrating communications functions with remote battery or solar powered single-chip data acquisition functions. An ultrasimplified and efficient form of SDR is also desirable, for implementation in smaller FPGA's or Application-Specific Integrated Circuits (ASICs).

The SDR should consist of a limited RF front end, followed by a high bandwidth analog/digital (A/D) (receive side) and digital/analog (D/A) (transmit side), and a final reprogrammable processing stage. Prototype hardware should be accompanied with a development system using commercially available and/or custom software with models of various components that can be used to simulate a communication system. The development system should be able to convert the computer-aided design/electronic design automation (CAD/EDA) model to firmware, and should include the hardware and software necessary to program the SDR. The SDR should be able to accommodate various NASA- and contractor-developed communication systems, which support surface-to-surface, space-to-space, and space-to-surface links, by reprogramming the SDR and with minimum RF front-end hardware changes.
Emphasis should be on reusable environmentally qualified components and development processes, which NASA can employ in integrated embedded systems, with the delivery of a complete SDR system serving primarily to validate the bidder’s proposed approach. Consideration should be given for any CAD/EDA or other commercial tools or components used as to suitability, configuration control, and maintainability for use in a long-duration mission-critical environment. Phase I proposals should demonstrate interoperability with at least one NASA communications system (such as, but not limited to, Space to Space Communications, Wireless Video System, Tracking and Delay Relay Satellite System Spaceflight Tracking and Data Network (TDRSS STDN), TDRSS Ku Band, etc.). Phase II should develop hardware and software that can be used in some on-going NASA project and provide interoperability with at least two communication systems.