NASA STTR 2012 Phase I Solicitation

T4 Robotics, Tele-Robotics and Autonomous Systems

The topic for Robotics, Tele-Robotics and Autonomous Systems, consists of seven technology subareas: Sensing and Perception; Mobility; Manipulation; Human-Systems Integration; Autonomy; Autonomous Rendezvous and Docking (AR&D); and Robotics, Tele-Robotics and Autonomous Systems Engineering. Robotics, Tele-Robotics and Autonomous Systems supports NASA space missions with the development of new capabilities, and can extend the reach of human and robotic exploration through a combination of dexterous robotics, better human/robotic interfaces, improved mobility systems, and greater sensing and perception. The Robotics, Tele-Robotics and Autonomous Systems topics focuses on several key issues for the future of robotics and autonomy: enhancing or exceeding human performance in sensing, piloting, driving, manipulating, and rendezvous and docking; development of cooperative and safe human interfaces to form human-robot teams; and improvements in autonomy to make human crews independent from Earth and make robotic missions more capable.

Subtopics

T4.01 Information Technologies for Intelligent and Adaptive Space Robotics

Lead Center: ARC

The objective of this subtopic is to develop information technologies that enable robots to better support space exploration. Robots are already at work in all of NASA's Mission Directorates and will be critical to the success of future exploration missions. The NASA "Robotics, Tele-Robotics, and Autonomous Systems" roadmap (TA04) indicates that extensive and pervasive use of robots can significantly enhance exploration, particularly for missions that are progressively longer, complex, and operate with fewer ground control resources.

Intelligent robots can do a variety of work to increase the productivity of planetary exploration. Robots can perform tasks that are highly-repetitive, long-duration, or tedious. Robots can perform tasks that help prepare for subsequent human missions. Robots can perform "follow-up" work, completing tasks started by astronauts. Example robotic tasks include:

- Scouting.
- Site surveys.

- Sampling.
- Payload deployment.
- EVA close-out work.

The performance of intelligent robots is directly linked to the quality and capability of the information technologies used to build and operate them. Thus, proposals are sought that address the following technology needs:

- Advanced user interfaces for telerobotics, which facilitate distributed collaboration, geospatial data visualization, summarization and notification, and robot tasking. This does NOT include user interfaces for direct teloperation (e.g., joystick-based rate control), telepresence, or immersive virtual reality. The primary objective is to enable more effective and efficient interaction with semi-autonomous telerobots. (TA04 roadmap technical area 4.4).
- Mobile robot navigation (localization, hazard detection and avoidance, etc) for operations in man-made and unstructured environments. Emphasis on multi-sensor data fusion, obstacle detection, and proximity ops. The primary objective is to radically and significantly increase the performance of mobile robot navigation through advanced on-board software. (TA04 roadmap technical areas 4.1 and 4.2).
- Robot software architecture that radically reduces operator workload for remotely operating planetary rovers. This includes frameworks for adjustable autonomy, on-board health management and prognostics, automated data triage, and high-performance robot middleware. The primary objective is to facilitate the creation, extensibility and maintenance of complex robot systems. (TA04 roadmap technical area 4.5).

T4.02 Dynamic Servoelastic (DSE) Network Control, Modeling, and Optimization

Lead Center: AFRC

Participating Center(s): ARC, JPL, LaRC

This subtopic addresses advanced control-oriented techniques for dynamic servoelastic (DSE) terrestrial, planetary, and space environment flight systems using distributed network sensor and control systems. Methods include modeling, simulation, optimization and stabilization of DSE systems to actively and/or adaptively control structural dynamic geometry/topology, vibration, atmospheric and intraspace disturbances, static/dynamic loads, and other structural dynamic objectives for enhanced dynamic servoelastic performance and stability characteristics.

- DSE control for performance enhancements while minimizing dynamic interaction.
- Flexible aircraft and spacecraft stabilization and performance optimization.
- Modeling and system identification of distributed DSE dynamics.
- Sensor/actuator developments and modeling for distributed DSE control.
- Uncertainty modeling of complex DSE system behavior and interactions.

- Distributed networked sensing and control for vehicle shape, vibration, and load control.

This subtopic also addresses capabilities enabling design solutions for performance and environmental challenges of future air and space vehicles. Research in revolutionary aerospace configurations include lighter and more flexible materials, improved propulsion systems, and advanced concepts for high lift/performance and drag/energy reduction. This subtopic targets efficiency and environmental compatibilities requiring performance challenges and novel control-oriented techniques for aero-servoelastic considerations which are gaining prevalence in

advanced aerospace flight vehicles, atmospheric and extra-terrestrial.

Technical elements for the Phase I proposals may also include:

- Mission/maneuver adaptivity with dissipative optimal energy-force distribution.
- Data-driven multi-objective DSE control with physics-based sensing.
- Robust sensing-control-communication networks for sensor-based distributed control.
- Compressive information-based sensing and information structures.
- Evolving systems as applied to self-assembling and robotic maneuvering.
- Scalable and evolvable information networks with layering architectures.
- Modular architectures for distributed autonomous aerospace systems.
- Multi-objective, multi-level control and estimation architectures.
- Distributed multi-vehicle dynamics analysis and visualization with complex simulations.

Development of distributed sensory-driven control-oriented DSE systems is solicited to enable future flight vehicle concepts and designs that manage structural dynamic uncertainty on a vehicle's overall performance. Proposals should assist in revolutionizing improvements in performance to empower a new generation of air and space vehicles to meet the challenges of terrestrial and commercial space concerns with novel concepts and technology developments in systems analysis, integration and evaluation. Higher performance measures include energy efficiency to reduce fuel burn and operability technologies that enable information network decompositions that have different characteristics in efficiency, robustness, and asymmetry of information and control with tradeoff between computation and communication.

Advanced mission applicability in Phase II should show the ability of aerospace GN&C systems to achieve mission objectives as a function of GN&C sensor performance, vehicle actuation/power/energy, and the ability to jointly design them as onboard-capable, real-time computing platforms with applicable environmental effects and robust guidance algorithms. Goals are to:

- Provide capabilities that would enable new projects/missions that are not currently feasible.
- Impact multiple missions in NASA space operations and science, earth science, and aeronautics.

- Be influential across aerospace and non-aerospace disciplines with dynamic interactions.

New technologies proposed should have the potential to impact the following NASA missions:

- Data availability for science missions.
- Mission planning.
- Autonomous rendezvous/docking technology.
- Environmental monitoring for human habitation.

Apart from NASA missions, the aeronautics technology could be adapted for development and use in autonomous operation of wind/ocean energy and smart space power grid systems in dynamic environments.

There are number of advantages to exploring this subtopic technology:

- Increase in autonomy and fuel efficiency of coordinated robotic vehicles and sub-components.
- Improved science, atmospheric, and reconnaissance data.
- Cost, risk and reliability of flight vehicles for a terrestrial, planetary, or space mission.
- Inter-networks with improved dynamic behavior.

Potential technical impacts are:

- Vehicle energy efficiency with passive/active dissipativity for control and dynamic stability with extreme power constraints.
- Weight minimization through dynamic servoelastic control.
- Missionadaptivity and robustness with real-time, consensus-coordinated control dealing with computation, communication, and dynamics.

T4.03 Extreme Particle Flow Physics Simulation Capability

Lead Center: KSC

Advanced computer modeling software is sought to provide the ability to predict the flow of granular materials in space and/or planetary environments. Proposals are sought for software capable of handling one of more of the following applications in one or more relevant environments for space exploration:

- Rovers driving on planetary regolith.
- Rocket engines blowing planetary regolith.
- Excavators and resource extraction systems moving and conveying planetary regolith.
- Technologies that burrow or drill into planets and asteroids for scientific access.
- Transport of granulated metal hydrides as hydrogen fuel systems.
- 3-D printing technologies that use powders in space manufacturing.

The relevant environments, or "extreme environments," are the environments encountered in space exploration but not normally encountered in terrestrial industry. These may include supersonic gas flow, rarefied atmospheres, low gravity, or zero gravity, where we have less terrestrial experience in the behaviors of granular flow.

This modeling capability will be useful as part of the engineering design and checkout process for aerospace systems, notably the technologies that will interact with planetary soil. The technologies that are sought are different than prior state-of-the-art (SOA) in granular modeling insofar as prior SOA often utilized ad hoc algorithms, empirical relationships, and "rules of thumb" to estimate granular behavior, and relied on "tweaking" model parameters until the modeling approximated experimental data over a limited range of application. (Granular flow is challenging due to meso-scale granularity that produces a bewildering array of emergent, macro-scale phenomena.) Prior SOA was therefore not truly predictive and therefore of limited power, but it was useful for modest extrapolation around a range of behaviors that has been previously validated by experiment. In contrast, advances in granular physics theory over the past 5 years are surprisingly far ahead of expectations and it is now possible to develop new modeling methods that are truly predictive for the previously unpredictable regimes of solid-like, fluid-like and gas-like flow of granular materials integrated with gas flow and mechanical devices, including extreme environments (rarefied/supersonic flow, planetary surfaces, etc.). While it is still too early to expect a software package to be capable of modeling all granular phenomena across all ranges of behavior and all environments, it is now possible to create software packages capable of handling one or more of the areas that are important to NASA and necessary for NASA's mission.

Relevant advances in granular physics that may be incorporated into the new software may include (but are not limited to):

- Granular gas theory equivalent to Boltzmann's Transport Equation.
- Application of granular gas theory to continuous particle size distribution to predict transport coefficients.
- Successful prediction of dense flow as a function of particle shape.
- A useful technology will be one that can be applied in the real-world engineering design process for the design and checkout of NASA spaceflight technologies.