Robotic Local Area Networks with Fault-Tolerant Distributed Layers for Real-Time Control

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Description

Lunar and Mars exploration missions will critically depend on heterogeneous and reconfigurable surface robotic teams to perform complex real-time tasks. Robotic teams necessitate innovative networks technology. Robotic networks must enable units to communicate with each other, must support real-time operations, and must guarantee safety, reliability, stability, and effectiveness. As a consequence, robotic networks will depend on distributed software layers that are tolerant to signal losses and adaptive to communication delays and jitter. However, tolerant and adaptive distributed control is currently performed only in industrial and academic research environments.

A primary objective for space robotic networks should be to develop, implement, and evaluate modular communication layers that will render robotic networks tolerant and adaptive to communication vagaries. The capability should enable an unprecedented degree of control of a networked physical environment in spite of fast physical dynamics, exogenous disturbances, and network vagaries. The proposed software layers should conform to the projected capabilities of radiation-tolerant hardware. Furthermore, the platform should be modular, re-usable across disparate applications, and consequently appropriate within a system-of-systems approach, sustainable, and affordable.

Technology Development Approach

The technology development should proceed in a series of steps, each of which addresses a specific technical challenge. Steps should interlace with each other. In particular, the validation steps should proceed by degrees and be paired with increasingly more complex simulators and emulators that model tasks, such as collaborative assembly.

Existing algorithms could be modified for NASA's robotic applications and verified via simulation as follows:

- *Sampling and Control Algorithms*. Sampling and control algorithms should use play-out buffers, control expiration times, signal pipelines, and observers to regularize the application of control signals and increase effectiveness and fault-tolerance.
- *Rate Control Algorithms*. Distributed end-point layers should regulate the generation and transmission of sampling and control packets depending both on physical dynamics and on network utilization constraints.

Next, a force-control simulator should be developed to mimic a remotely force-controlled robot during representative tasks (e.g., manipulation for assembly). Increasingly more complex simulations will enable the flexible and continuous evaluation of the approach from its earliest stages. The simulator can be exercised for evaluation, robustness, and tuning, where play-back intervals, time-out values, and congestion control parameters can be tuned and evaluated in terms of robustness and advanced technology readiness. The evaluation should take place on computing and communication platforms that have capabilities comparable to those of radiation-tolerant devices at the time that the project matures.

A potential product could be a network of force-controlled robot arms for manipulation task emulation, which can be networked and use the proposed communication layers to execute a representative manipulation task. The emulation will evaluate the technology on a physical test-bed and in the presence of communication disruptions. A final tangible demonstration could involve the remote control of a collaborative robotic assembly task, such as the multi-arm coordinated manipulation of a solar panel.

The expected overall outcome will consists of a modular software platform for robotic communication that enables system stability and tracking in spite of network delays, losses, and jitter. We submit that this platform would constitute the fundamental end-to-end building block to robotics networks much like TCP is the backdrop of terrestrial bulk transfers.

Impact on Future Exploration

The capability would enable multi-robotic teams to associate in vehicle and surface wireless local area networks and communicate reliably in real-time with each other and with rovers, landers, and habitats. Other potential maturation paths include orbital multi-robotic team communication, locally tele-operated systems and remotely tele-supervised robots, the on-board interconnection of heterogeneous sensing, control, and actuation units on future spacecrafts.