NASA H&RT BAA-04-02

Modular, Multifunctional and Reconfigurable SuperBot

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Project Abstract

One of the most challenging issues for human-centered long-range space exploration is performing complex tasks in environments that are not human-friendly. These tasks range from extravehicular activities (EVA) such as inspection, maintenance, and assembly, to surface landing, exploration, and habitat-construction. A robotic solution is essential to meeting this challenge. However, the traditional approach of building separate robots for separate tasks (such as the Canada Arm and surface rovers) may no longer be adequate for affordable space exploration as the required robotic tasks become diverse and the need to pack many functionalities into a single launch volume increases.

This proposal is to build a system of systems solution to space robots by constructing a super robot, SuperBot, that is modular, multifunctional, and reconfigurable for different tasks at different mission stages. SuperBot modules are extreme examples of "design for reuse." The SuperBot can reconfigure into an "extended arm" for extravehicular inspection and maintenance; then reconfigure into multiple "flying eye/hands" for in-vehicle crew assistance and autonomous health monitor and management. At the destination orbit, the robot can optimally pack itself in a landing capsule either to reduce the landing volume or protect other valuable instruments or equipment. On the surface, it may morph into a "rover" to explore a flat environment, a "climber" to go down and up a crater, or a mobile "platform" to perform applications such as drilling, building, or sample collection. It may also perform exterior inspection of a habitat, or tend to the growing of plants inside a greenhouse.

SuperBot will be made of many autonomous, intelligent, and self-reconfigurable modules and the system will interact with humans to detect unexpected module failures and repair malfunctions by reconfiguration. Within the scope of this project, we will build a SuperBot robot that consists of 100 reconfigurable modules and demonstrate it in a desert in four very distinct configurations/functionalities, including their reconfigurations from one to another. The four configurations are: (1) a "contracted" configuration for transportation and landing, (2) a "rolling" configuration for traveling on flat terrain, (3) a "climbing" configuration for climbing and descending slopes, and (4) a "platform" configuration for performing applications such as drilling, building, sample collection, or sustaining living. In the final demonstration, the SuperBot will start from a contracted configuration, reconfigure into to a rolling configuration, travel a distance to a sand dune, reconfigure into a climbing configuration, climb the sand dune to the top, reconfigure into a platform, and sustain a set of carried seeds for a period of time until they grow into

sprouts. We will also demonstrate the flying ability of a single SuperBot module in a relevant micro-gravity testing facility.

The SuperBot project will be built upon the first spiral of the development completed in the last decade with small-scale, earth-oriented prototype self-reconfigurable robots by the proposing team, with total support of more than $8M from DARPA, AFOSR, NSF, and NASA. The technologies developed include: a) a set of Lego-like robotic modules that are autonomous (each has power, sensors, actuators, communications, and control), technology for structural reconfigurability (with docking mechanisms), and plug-and-play functionalities; b) interfaces and mechanisms capable of self-transforming these autonomous modules into different configuration for different applications, and c) a very flexible and powerful distributed software control architecture (US Patent #6636781) for communicating, sensing and responding to internally and externally generated tasks. The proposed SuperBot project will begin with these TRL5 component technologies and build a TRL6 prototype demonstration for space relevant conditions.

The key issue for this maturation project is to balance the homogeneous control structure/interface for module reconfiguration (with shared power and communication) and the heterogeneous hardware/software for special capabilities, and to enable the robot to accomplish space-relevant missions autonomously or under human commands. In particular, the new challenges for the SuperBot system include:

- *Flexible*: to design new modules and connectors for arbitrary reconfigurations;
- *Robust*: to enable modules to function and reconfigure in space-relevant environments;
- *Adaptive*: to select and change configuration according to the environmental conditions;
- *Reliable*: to detect and recover from unexpected failures under human instructions;
- *Interactive*: to accept and execute high level commands for execution and reconfiguration without requiring detailed instructions to individual modules;
- *Heterogeneous*: to develop new hardware and control protocols for interfacing other types of devices and reconfigure with these devices;
- *Integration*: to interface with the existing NASA robot command software systems.

The impact of SuperBot is to offer an effective and affordable solution based on modularity and reconfigurability for NASA's many different robotic tasks and functionalities demanded by sustained space exploration. The concepts can also be applied to other desirable system features such as reusable designs, modularity, autonomy and the easing of logistics. As NASA plans repeated and extended access to planetary surfaces, the reuse of robotic components can greatly reduce cost and ease operations and the logistics trail. The interchangability of robotic components will decrease the need for redundant parts (thus reducing payload mass) and enhance mission reliability and safety by allowing robust reconfigurability in times of failure.