Strategies for Using SuperBots on the Lunar Surface

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Our research at the Hawai'i Institute of Geophysics and Planetology, University of Hawai'i, focused on developing scenarios for using SuperBots in lunar exploration. We did this in collaboration with others on the SuperBot team, including colleagues from SuperBot Headquarters at ISI/USC, Ames Research Center, Lockheed Martin, and DigitalSpace. We identified three major uses of SuperBot technology. These uses are not mutually exclusive.

1. SuperBot MULE (Multi-Use Lunar Explorer)
2. SuperBot Mini-MIS (Mini-Mobile Investigation System)
3. SuperBot HOMS (Habitat Operations and Maintenance System)

We discuss each of these concepts below.

SUPERBOTS ON THE LUNAR SURFACE: A ROBOTIC MULTI-USE LUNAR EXPLORER (MULE)

Introduction:

Our vision of a SuperBot autonomous explorer and astronaut assistant is called the Multi-Use Lunar Explorer (MULE). The fundamental idea is to set up ~120 SuperBot modules on a rover chassis and, with a few specialized tools, use and reuse these modules to accomplish a variety of geologic and resource exploration tasks on the lunar surface and subsurface, with or without the help of astronauts.

Reconfigurability of the SuperBot modules is the key to their success. MULE modules can combine in a variety of ways to perform multiple tasks during different mission stages (Fig.1). For example, one level of a toolbox (12 SuperBot modules) can reconfigure to make a trenching arm, which can later reconfigure to make an element of a seismic network.

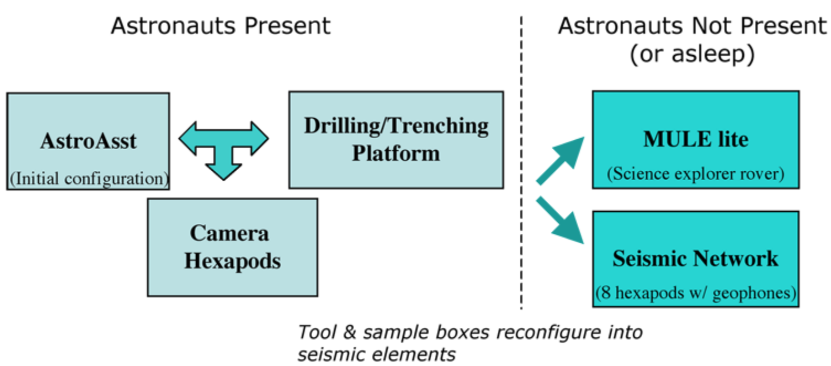

Fig. 1 Example reconfigurations to maximize the utility of the MULE system.

Only a few specialized components (e.g. scoop, geophone, cameras, etc.), built with common docking interfaces, can transform an arrangement of identical SuperBot modules into versatile tools. We highlight below some of the tasks planned for MULE as an astronaut assistant and as an autonomous explorer.

Astronaut Assistant:

In its initial configuration, we envision the MULE as a pack mule, aiding the astronauts during their EVAs (Fig. 2). MULE would begin by carrying the bulk of the SuperBot modules in two box configurations around metal liners: each would consist of 60 SuperBot modules, 3 modules per side and stacked 5 layers high. The boxes could be used by astronauts for rock sample storage and carrying simple tools (rock hammer, shovels, rakes, scoops, etc.).

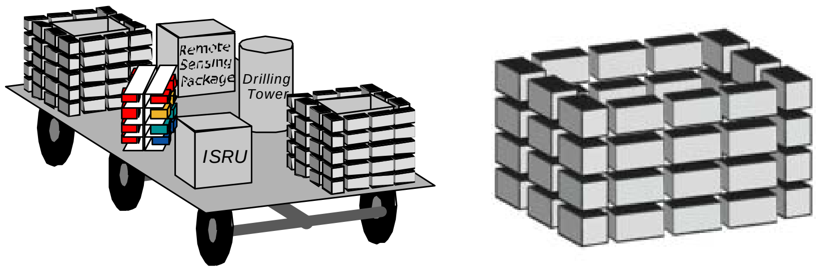

Fig. 2. Left: Schematic drawing of initial configuration of MULE with SuperBot modules in twin box configurations, illustrated larger in drawing on the right.

As a deep drilling platform, we envision a specialized drill system, to help investigate the lunar subsurface, anchored to a platform of SuperBots and stabilized by SuperBot-constructed legs. To further assist in geologic and resource exploration, we envision the MULE with a scientific instrument package on board (e.g. multispectral cameras), programmable by the astronauts to carry out measurements that may need long integration times or that are in astronaut-inaccessible locations.

The MULE could also offer significant safety features for the astronauts by carrying extra air and consumables, rescuing fallen or injured astronauts, or even acting as an emergency shelter for radiation shielding.

Autonomous Explorer:

The MULE would also act autonomously before astronauts arrive, after they leave, or during the mission while they are asleep. As part of exploring the lunar subsurface, we envision a shallow trenching device consisting of an arm made of SuperBot modules and a specialized terminal scoop or bucketwheel (Fig. 3). The depth of the trench could be increased by simply adding more modules to the arm, while the trench width and length would be controlled by MULE movement. This arm could simultaneously dump scoops of regolith into an on-board ISRU experiment.

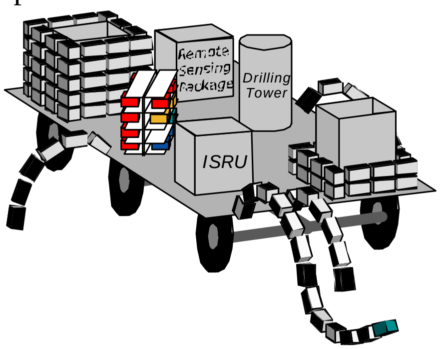

Fig. 3. Schematic of the MULE with stabilizing legs and trenching arm deployed. Teal block represents specialized module at the end of the arm, either a scoop or bucketwheel.

An additional scientific SuperBot project would be the deployment of components of the Mini-MIS. Afer the Mini-MIS tasks are completed, they could return to the MULE for use in other functions.

Other MULE tasks:

MULE could also perform other tasks, including: long-distance or rough-terrain mapping or reconnaissance, rock sample collection and return, E/PO teleoperation exercises for Earth-bound students, and photo-documentation (either autonomously or teleoperated) of mission events and astronaut activities for historical or artistic purposes.

SUPERBOTS ON THE LUNAR SURFACE: MINI-MOBILE INVESTIGATION SYSTEM (MINI-MIS)

The Mini-MIS concept:

One particularly appealing near- and long-term application is to use SuperBots as small, inexpensive, highly capable mobile platforms for science investigations. We call the concept Mini-Mobile Investigation System (Mini-MIS). The fundamental idea is that sets of 8 to 10 SuperBot modules would reconfigure to form a mobile platform with a specialized science or exploration device included inside a module or attached as a separate specialized module. The module set (Mini-MIS) would be able to reconfigure itself depending on the mobility or instrument deployment needs: wheels (for efficient travel), spiders or centipedes (for climbing), snakes (for burrowing), towers for communications (Fig. 4).

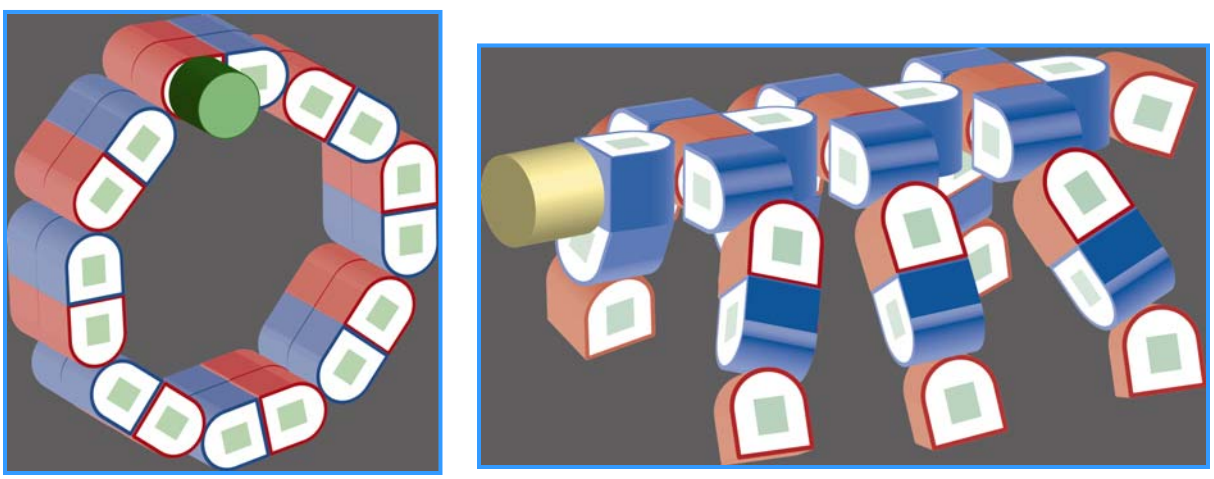

Fig. 4. Two configurations of Mini-MIS, each equipped with a specialized module (shown in green or gold) for scientific observations or other exploration functions.

Mini-MIS modules can combine in a variety of ways as they move across the lunar surface. For delivery to the Moon, they can be efficiently packed into cubes, or disseminated throughout a lander. For deployment, the modules would assemble into one or more Mini-MIS platforms and crawl off the lander autonomously. We highlight below some near-term investigations where the Mini-MIS can greatly enhance lunar exploration.

Mini-MIS Polar Explorer:

The lunar Polar Regions are enriched in hydrogen, possibly in the form of H_2O ice trapped in permanently shadowed regions. This may constitute a valuable resource for propellant production on the Moon. However, the abundance, form (crystalline or amorphous ice), concentrations of impurities (CH_4, CO, NH_3, etc.), and spatial distribution of the H_2O are not known. Prospecting for the resource requires measurements in more than one location to provide a statistically sound sampling of a region (Fig. 5). This implies a rover, yet mission budget constraints might prohibit a large, robust rover. Thus, a resource survey involving a lander in one location would be greatly enhanced by using SuperBots as inexpensive rovers that could carry specialized modules to search for water over distances of a few kilometers. Two Mini-MIS assemblages could move in orthogonal directions from a lander, sampling every 100-200 meters.

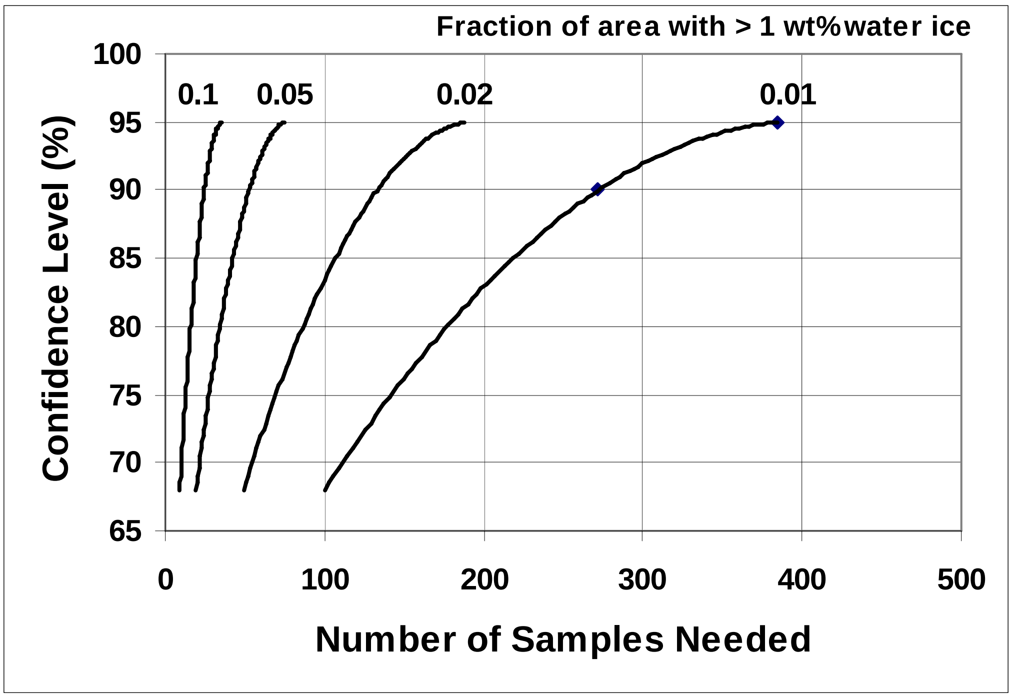

Fig. 5. Calculation of the number of sampling sites needed to prove an economically useful amount of water is not present at the indicated level of confidence. Curves represent the spatial abundance (in fraction of surface covered) of randomly placed patches of water ice. Even for abundant water ice (0.1 curve), tens of samples are needed. So many samples would be aided by use of a Mini-MIS equipped with a water detector such as a Raman spectrometer.

Mini-MIS Resource Prospector:

Mini-MIS could also carry a chemical analytical device to measure the concentration of marker elements for specific types of potentially useful deposits. Examples are measuring (1) the concentration of Zr, K, or P to find deposits rich in KREEP components, representing the last chemical remnants of the magma ocean (2) Cl or F to find enrichments of volatile sublimates in volcanic glass deposits.

Mini-MIS Active Seismic Surveyor:

The structure of the upper few hundred meters of the lunar surface is not characterized quantitatively. We believe that a network of 6-10 Mini-MIS consisting of 6-8 Superbot modules, each with a specialized geophone attached, could autonomously deploy itself into multiple, reconfigurable lines or arrays to map the lunar subsurface (Fig. 6). Small triggered-explosives or an electronic source located on a rover would be used as a source for seismic signals. The Mini-MIS seismic surveyor could map typical regolith areas and impact crater structures and deposits.

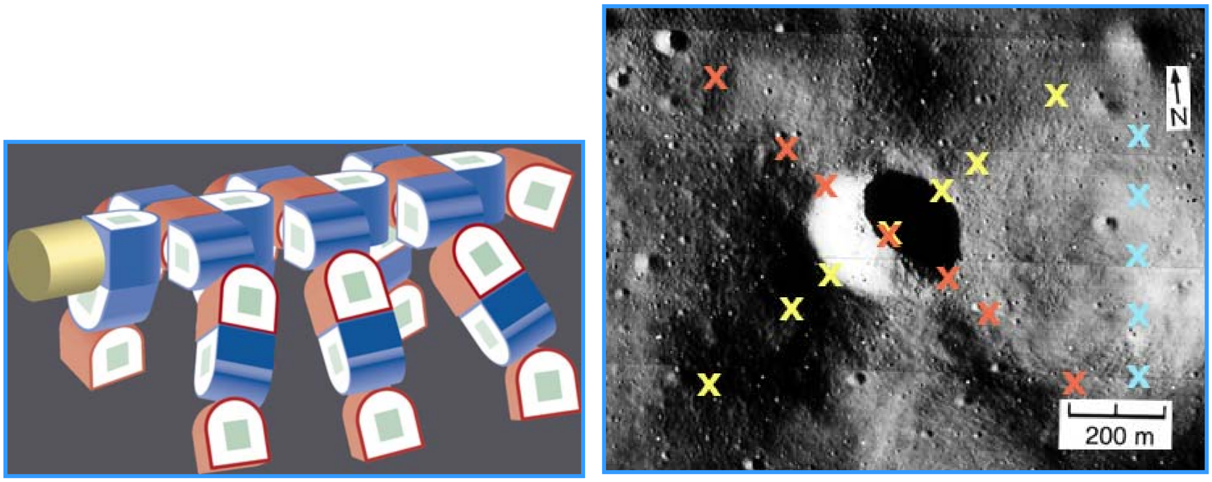

Fig. 6. Seft: Schematic of a hexapod configuration of SuperBot modules with a specialized geophone module on the front (gold cylinder). Right: An example of three different self-deployed arrays for several SuperBot hexapod seismic network elements. Hexapods can reconfigure into other shapes to facilitate travel across lunar surface or to bury geophones.

Mini-MIS Navigation Beacons:

Mini-MIS could be used as beacons for local navigation on the lunar surface (Fig. 7). A Mini-MIS beacon could climb a local hill to broadcast or relay signals, allowing astronauts to traverse in a rover out of sight of the lunar outpost.

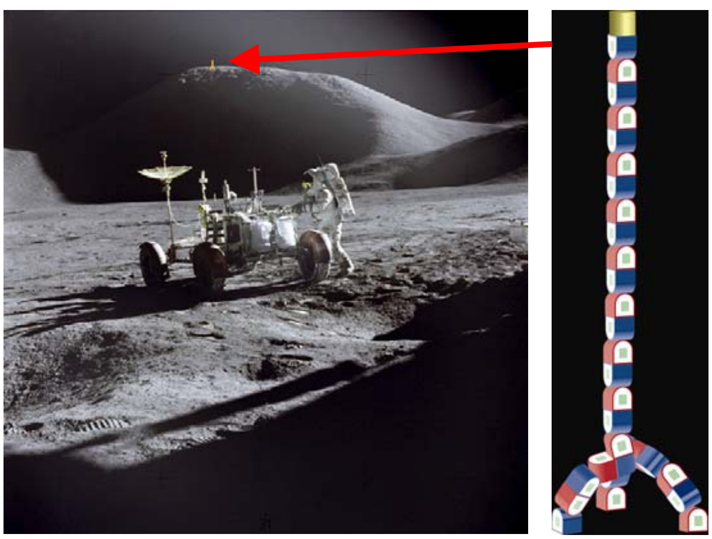

Fig. 7. Mini_MIS communications relay placed on a hill allows over-the-horizon communication with other explorers (robotic and human).

SuperBots on the Lunar Surface:
Habitat Operations and Maintenance (HOMS)

Introduction:

For the foreseeable future, astronaut extravehicular activity (EVA) time will be at a premium on the lunar surface. It is neither practical nor desirable to expect astronauts to perform all extravehicular functions during the course of a lunar mission. However, many of the expected tasks at a lunar facility will require extensive EVA time. Therefore, a need exists for a robust robotic system that can accomplish an assortment of EVA tasks while controlled by either the crew or from the ground.

The HOMS Concept:

Our vision of a SuperBot teleoperated habitat inspection and repair system is called the Habitat Operations and Maintenance System, or HOMS. This concept involves the use of ~150 SuperBot modules in concert with each other and a few specialized tools (such as cameras and scoops). These modules are then used and reconfigured to accomplish a range of tasks on the lunar surface. For example, the same 10 SuperBot modules can be reconfigured to make an excavation arm for ISRU purposes or a small, instrumented walker for habitat inspection. This use of specialized components with common docking interfaces, such as patch kits or cameras, transforms groups of identical SuperBot modules into versatile tools.

Logistics:

The HOMS system could configure as a set of legs or wheels to move supply pallets from landed cargo elements to the outpost (Fig. 8). Alternatively, the HOMS system could also be used to transfer consumables from one part of a lunar outpost to another (i.e., from the oxygen propellant plant to the outpost). By configuring as manipulator arms, HOMS could also handle routine tasks in the resupply of spacecraft consumables, such as connecting and disconnecting external fuel lines.

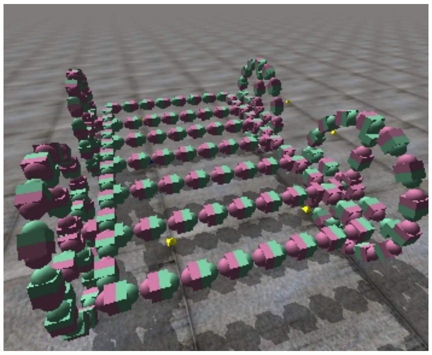

Fig. 8: HOMS system configured as a cargo carrier. (Image: ISI)

Operations and Maintenance:

The HOMS system is ideally suited for (1) dust mitigation, such as microwave sintering of areas (using SuperBot walkers equipped with specialized microwave modules) surrounding the habitat (Fig. 9), (2) in-situ solar panel production (3) solar panel cleaning (using SuperBot walkers equipped with brushes), (4) real-time monitoring and inspection of habitats and landed spacecraft (using walkers equipped with cameras), (5) outpost navigational beacons (6) nuclear reactor operations and (7) repair of habitats and spacecraft. For example, HOMS could be used to inspect and refuel surface nuclear reactors, minimizing the danger to human life.

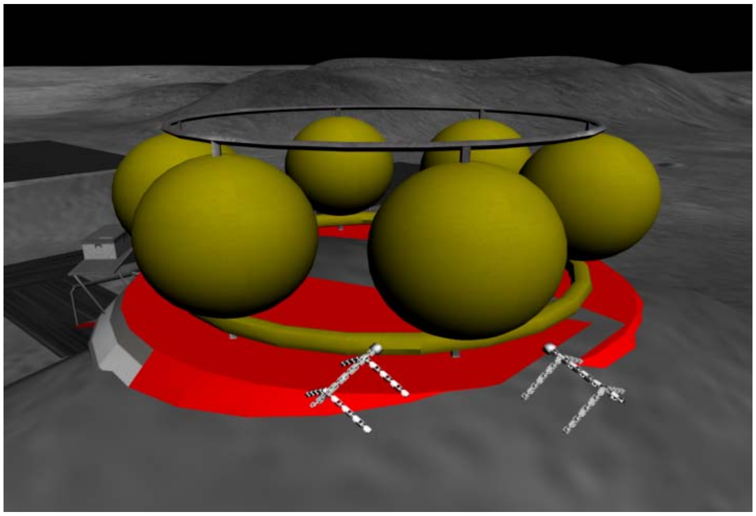

Fig. 9: Two instrumented SuperBot walkers inspect a leaking oxygen tank. (Image by S. Lawrence, HIGP; digital models by DigitalSpace)

Construction:

At early lunar outposts, the HOMS system in the form of multiple SuperBot walkers with scoops could be used to provide a significant regolith mass excavation capability. This would be useful for the construction of foundations, grading roadbeds (Fig. 10), running power lines, and creating emergency radiation storm shelters for the crew.

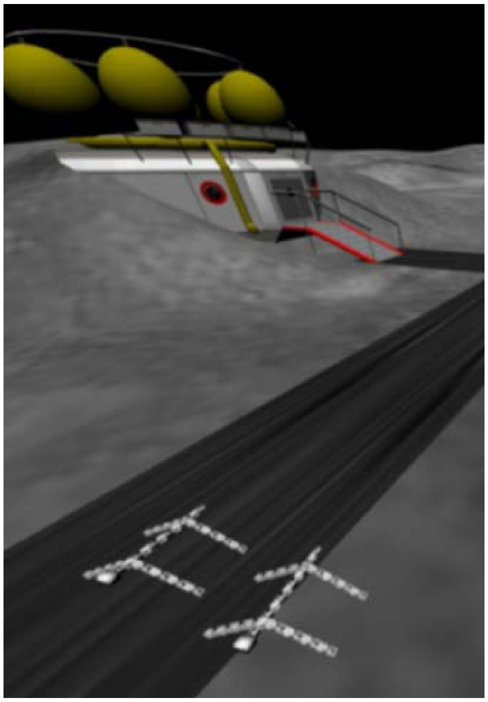

Fig. 10: Two SuperBot HOMS walkers inspect a microwave sintered roadway. (Image by S. Lawrence, HIGP; digital models by DigitalSpace)

ISRU:

The HOMS system could be used to provide regolith feedstock to ISRU pilot plants on the early missions. This could be performed in two ways: 1) Using multiple SuperBot walkers equipped with scoops or as legs to allow active reconfiguration of a larger modular conveyor belt system.

Conclusion:

The HOMS concept has countless applications at lunar outposts. The high degree of hardware commonality between the HOMS system and the Mini-MIS, and MULE SuperBot, as well as any SuperBot variants designed for orbital and cislunar operations, leverages technology development costs across a wide array of mission types while promoting ease of repair and lowering costs. The SuperBot HOMS system offers a pathway towards flexible and robust human lunar surface operations and economical lunar surface development.