Stanford researchers develop acrobatic space rovers to explore moons, asteroids

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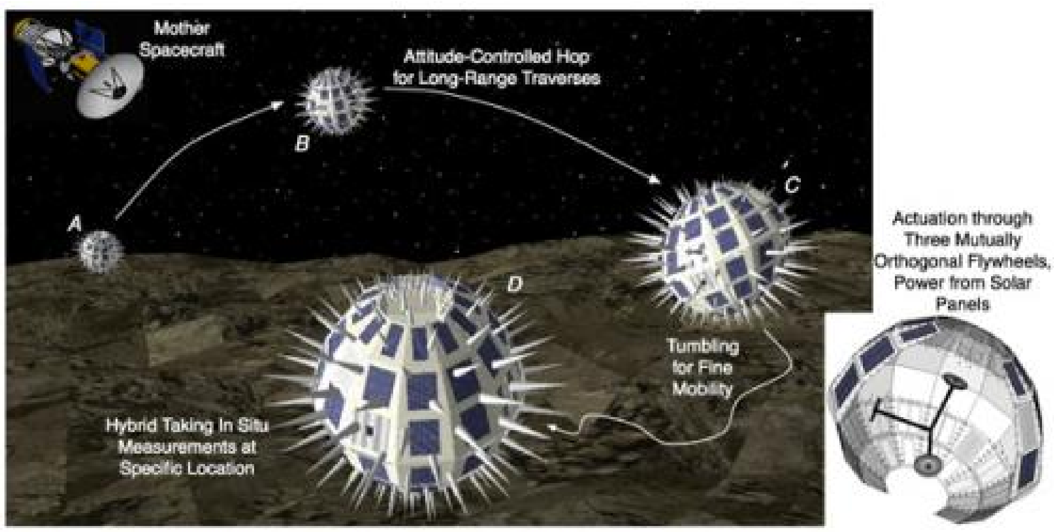

Illustration of how the mother spacecraft Phobos Surveyor and its 'hedgehogs' would work.

(Phys.org)—Stanford researchers, in collaboration with NASA's Jet Propulsion Laboratory and the Massachusetts Institute of Technology, have designed a robotic platform that could take space exploration to new heights.

The mission proposed for the platform involves a mother spacecraft deploying one or several spiked, roughly spherical rovers to the Martian moon Phobos. Measuring about half a meter wide, each rover would hop, tumble and bound across the cratered, lopsided moon, relaying information about its origins, as well as its soil and other surface materials.

Developed by Marco Pavone, an assistant professor in Stanford's Department of Aeronautics and Astronautics, the system relies on a synergistic relationship between the mother spacecraft, known as the Phobos Surveyor, and the rovers it houses, called "hedgehogs." The Phobos Surveyor, a coffee-table-sized vehicle flanked by two umbrella-shaped solar panels, would orbit around Phobos throughout the mission. The researchers have already constructed a prototype.

The Surveyor would release only one hedgehog at a time. Together, the mothership and hedgehogs would work together to determine the hedgehog's position and orientation. Using this information, they would map a trajectory, which the mother craft would then command the hedgehog to travel.

In turn, the spiky explorers would relay scientific measurements back to the Phobos Surveyor, which would forward the data to researchers on Earth. Based on their analysis of the data, the scientists would direct the mothership to the next hedgehog deployment site.

An entire mission would last two to three years. Just flying to Phobos would take the Surveyor about two years. Then the initial reconnaissance phase, during which the Surveyor would map the terrain, would last a few months. The mothership would release each of the five or six hedgehogs several days apart, allowing scientists enough time to decide where to release the next hedgehog.

For many decisions, Pavone's system renders human control unnecessary. "It's the next level of autonomy in space," he said.

Moon clues

The synergy between the Phobos Surveyor and the hedgehogs would also be reflected in their sharing of scientific roles. The Surveyor would take large-scale measurements, while the hedgehogs would gather more detailed data. For example, the Surveyor might use a gamma ray or neutron detector to measure the concentration of various chemical elements and compounds on the surface, while the hedgehogs might use microscopes to measure the fine crevices and fissures lining the terrain.

Although scientists could use the platform to explore any of the solar system's smaller members, including comets and asteroids, Pavone has designed it with the Martian moon Phobos in mind.

An analysis of Phobos' soil composition could uncover clues about the moon's origin. Scientists have yet to agree on whether Phobos is an asteroid captured by the gravity of Mars or a piece of Mars that an asteroid impact flung into orbit. This could have deep implications for our current understanding of the origin and evolution of the solar system, Pavone said.

To confirm Phobos' origins, Pavone's group plans to deploy most of the hybrids near Stickney Crater. Besides providing a gravity "sweet spot" where the mother craft can stably hover between Mars and Phobos, the crater also exposes the moon's inner layers.

A human mission to Mars presents hefty challenges, mainly associated with the planet's high gravity, which heightens the risk of crashing during takeoffs and landings. The large amounts of fuel needed to overcome Mars' strong pull during takeoffs could also make missions prohibitively expensive.

But Phobos' gravity is a thousand times weaker than on Mars. If Phobos did indeed originate from the red planet, scientists could study Mars without the dangers and costs associated with its high gravity simply by sending astronauts to Phobos. They could study the moon itself or use it as a base station to operate a robot located on Mars. The moon could also serve as a site to test technologies for potential use in a human mission to the planet.

"It's a piece of technology that's needed before any more expensive type of exploration is considered," Pavone said of the spacecraft-rover hybrid. "Before sampling we need to know where to land. We need to deploy rovers to acquire info about the surface."

Making the most of low gravity

Today's rovers have trouble operating in the low gravity environment characteristic of small celestial objects. For example, such conditions can cause the wheels of mobile platforms to lose traction and spin uncontrollably. Pavone's team has designed the hybrid system to exploit low gravity by relying primarily on airborne motion.

The hedgehogs do not have wheels, as do the current Mars rovers. Instead they rely on three rotating discs enclosed within each hedgehog, with each disc pointing in a different direction.

In the microgravity of Phobos, the inertial forces of the spinning disks allow the hedgehogs to move nimbly and precisely in environments that would leave other robots bouncing or floating uncontrollably. Quickly accelerating the discs causes the hedgehog to hop, while spinning them even faster results in a bound. Accelerating the discs just slightly makes the hedgehogs tumble, ideal for fine maneuvering.

The team has already built and tested two generations of rover prototypes and are developing a third. Although the third generation is cubical, the geometry of future generations will include more facets, ultimately making the rover close to sphere-shaped.

Designing the hedgehogs for Phobos' uneven surface has proven tricky. "You can get into very hard rocky terrain, or very soft, almost like powder, terrain," said doctoral candidate Ross Allen. "Whatever's touching the ground needs to get traction on hard stuff without getting stuck on soft stuff... That's something that will require more work and testing."

Pavone's team is developing test sites to mimic low-gravity conditions as closely as possible. Next summer, the researchers plan to test the third-generation hedgehog, using a large overhead crane at the Durand Building at Stanford. The scientists will secure a hedgehog into the crane's harness, which is attached to a spring device that will offload weight from the hedgehog.

Although the crane is ready to go at Durand, the researchers need to haul in rocks and dirt to replicate obstacles the rovers might encounter on Phobos. Flour will serve as a stand-in for asteroid dust.

Eventually, the team plans to test the hedgehogs in a reduced-gravity aircraft, also known as a "vomit comet," essentially an airplane flying a parabolic path. The plane climbs and then pitches downward, at which point it begins a low-gravity free-fall lasting about 25 seconds before pulling up again. During each parabola, the researchers will test a different hedgehog maneuver.

A test of the Phobos Surveyor will likely take place in two to four years.

Pavone hopes that a Phobos Surveyor mission, which could occur within the next 10-20 years, will bring scientists closer to a human mission to Mars. "The bottom line is that there is a growing interest in the exploration of small bodies," he said.

Scientists may first need to understand the chemical composition and mechanical properties of these smaller members of the solar system before safe, cost-effective planetary missions can take place, he added.

The researchers initiated the spacecraft-rover project as part of the NASA Innovative Advanced Concepts Program. They will present a paper describing their platform's proposed mission at the Institute of Electrical and Electronics Engineers Aerospace Conference in March.

Provided by Stanford University

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