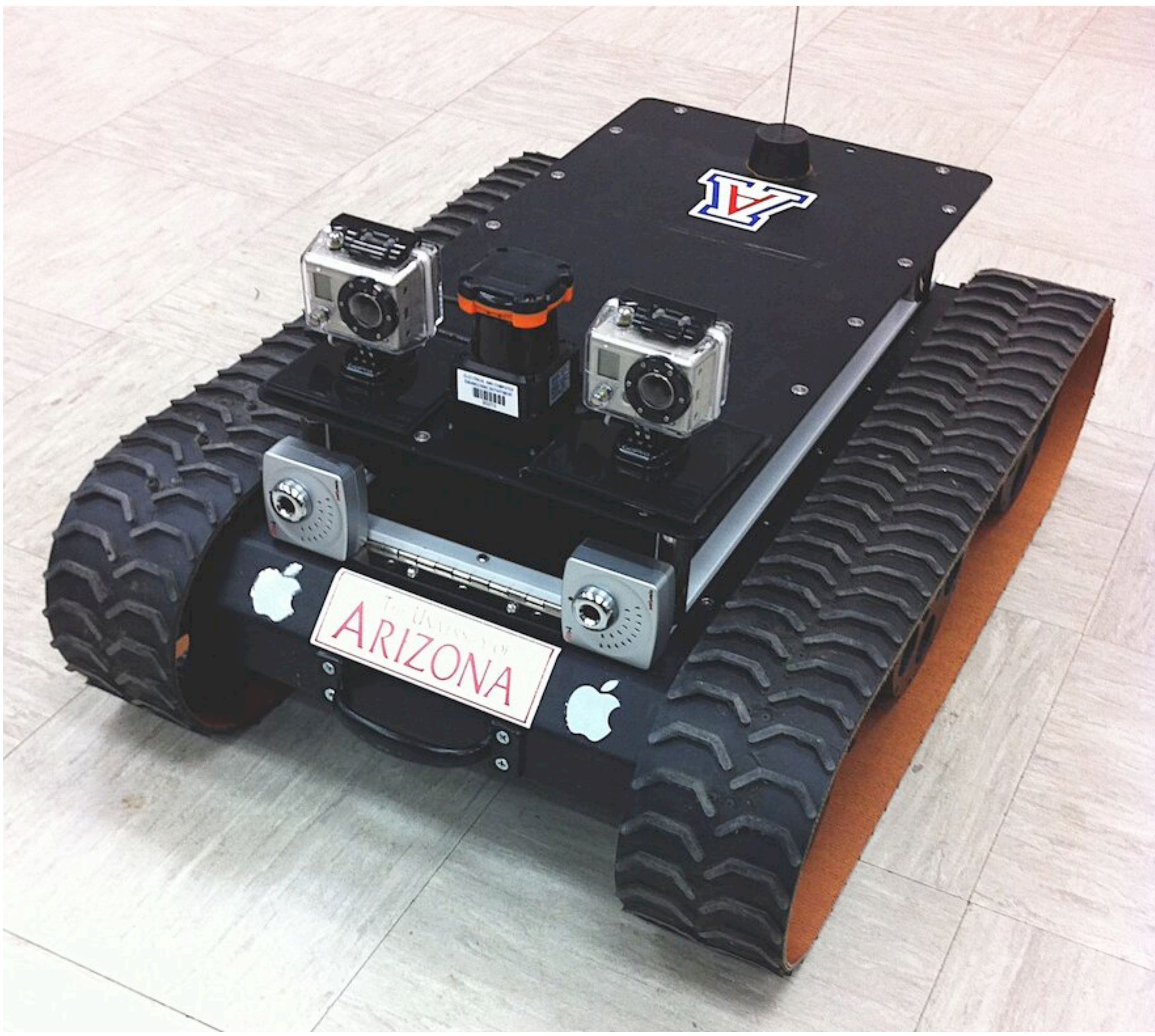
Hansel and Gretel's breadcrumb trick inspires robotic exploration system for caves on Mars and beyond

March 1 2023, by Daniel Stolte



One of the experimental rovers used by Fink's team to test hardware and software related to autonomous exploration. This prototype is outfitted with cameras and other sensors for navigation. Credit: Wolfgang Fink/University of Arizona

House hunting on Mars could soon become a thing, and researchers at the University of Arizona are already in the business of scouting real estate that future astronauts could use as habitats. Researchers in the UArizona College of Engineering have developed technology that would allow a flock of robots to explore subsurface environments on other worlds.

"Lava tubes and caves would make perfect habitats for astronauts because you don't have to build a structure; you are shielded from harmful cosmic radiation, so all you need to do is make it pretty and cozy," said Wolfgang Fink, an associate professor of electrical and computer engineering at UArizona.

Fink is lead author of a new paper in *Advances in Space Research* that details a communication network that would link rovers, lake landers and even submersible vehicles through a so-called mesh topology network, allowing the machines to work together as a team, independently from human input. According to Fink and his co-authors, the approach could help address one of NASA's Space Technology Grand Challenges by helping overcome the limited ability of current technology to safely traverse environments on comets, asteroids, moons and planetary bodies. In a nod to the fairy tale "Hansel and Gretel," the researchers named their patent-pending concept the "Breadcrumb-Style Dynamically Deployed Communication Network" paradigm, or DDCN.

A fairy tale inspires the future

"If you remember the book, you know how Hansel and Gretel dropped breadcrumbs to make sure they'd find their way back," said Fink, founder and director of the Visual and Autonomous Exploration Systems Research Laboratory at Caltech and UArizona. "In our scenario, the 'breadcrumbs' are miniaturized sensors that piggyback on the rovers, which deploy the sensors as they traverse a cave or other subsurface environment."

Continuously monitoring their environment and maintaining awareness of where they are in space, the rovers proceed on their own, connected to each other via a wireless data connection, deploying communication nodes along the way. Once a rover senses the signal is fading but still within range, it drops a communication node, regardless of how much distance has actually passed since it placed the last node.

"One of the new aspects is what we call opportunistic deployment—the idea that you deploy the 'breadcrumbs' when you have to and not according to a previously planned schedule," Fink said.

All the while, there is no need for input from the mother rover; each subordinate rover will make that determination on its own, Fink added. The system can work in one of two ways, Fink explained. In one, the mother rover acts as a passive recipient, collecting data transmitted by the rovers doing the exploration. In the other, the mother rover acts as the orchestrator, controlling the rovers' moves like a puppet master.

A hole in the surface of Mars, spotted by the HiRISE camera, reveals a cave below. Protected from the harsh surface of Mars, such pits are believed to be good candidates to contain Martian life, making them prime targets for possible future spacecraft, robots and even human interplanetary explorers. Credit: NASA/JPL/University of Arizona

Machines take over

The new concept dovetails with the tier-scalable reconnaissance paradigm devised by Fink and colleagues in the early 2000s. This idea envisions a team of robots operating at different command levels—for example, an orbiter controlling a blimp, which in turn controls one or more landers or rovers on the ground. Already, space missions have embraced this concept, several with participation by UArizona researchers. For example, on Mars, the Perseverance rover is commanding Ingenuity, a robotic helicopter.

A concept for another mission, which ultimately was not selected for funding, proposed sending an orbiter carrying a balloon and a lake lander to study one of the hydrocarbon seas on Saturn's moon Titan. The breadcrumb approach takes the idea one step further by providing a robust platform allowing robotic explorers to operate underground or even submerged in liquid environments. Such swarms of individual, autonomous robots could also aid in search and rescue efforts in the wake of natural disasters on Earth, Fink said.

Fink said the biggest challenge, apart from getting the rovers inside the subsurface environment in the first place, is to retrieve the data they record underground and bring it back to the surface. The DDCN concept allows a team of rovers to navigate even convoluted underground environments without ever losing contact to their "mother rover" on the surface. Outfitted with a light detection and ranging system, or lidar, they could even map out cave passages in all three dimensions, not unlike the drones that can be seen exploring an alien spacecraft in the movie "Prometheus."

"Once deployed, our sensors automatically establish a nondirected mesh network, which means each node updates itself about each node around it," said Fink, who first detailed the DDCN concept in a proposal to NASA in 2019.

"They can switch between each other and compensate for dead spots and signal blackouts," added Mark Tarbell, paper co-author and senior research scientist in Fink's laboratory. "If some of them die, there still is connectivity through the remaining nodes, so the mother rover never loses connection to the farthest node in the network."

In this artist's impression of the breadcrumb scenario, autonomous rovers can be seen exploring a lava tube after being deployed by a mother rover that remains at the entrance to maintain contact with an orbiter or a blimp. Credit: John Fowler/Creative Commons, Mark Tarbell and Wolfgang Fink/University of Arizona

Mission of no return

The robust network of communication nodes ensures all the data collected by the robotic explorers make it back to the mother rover on the surface. Therefore, there is no need to retrieve the robots once they have done their job, said Fink, who published the idea of using groups of expendable mobile robotic surface probes as early as 2014.

"They're designed to be expendable," he said. "Instead of wasting resources to get them into the cave and back out, it makes more sense to have them go as far as they possibly can and leave them behind once they have fulfilled their mission, run out of power or succumbed to a hostile environment."

"The communication network approach introduced in this new paper has the potential to herald a new age of planetary and astrobiological discoveries," said Dirk Schulze-Makuch, president of the German Astrobiological Society and author of many publications on extraterrestrial life. "It finally allows us to explore Martian lava tube caves and the subsurface oceans of the icy moons—places where extraterrestrial life might be present."

The proposed concept "holds magic," according to Victor Baker, a UArizona Regents Professor of Hydrology and Atmospheric Sciences, Geosciences and Planetary Sciences. "The most amazing discoveries in science come about when advances in technology provide both first-time access to a thing or place and the means of communicating what is thereby discovered to creative minds that are seeking understanding," Baker said.

Exploring hidden ocean worlds

In places that call for submersible robots, the system could consist of a lander—either floating on a lake, as might be the case on Titan, or sitting on the ice atop a subsurface ocean like on Europa—that is connected to the submarine, for example through a long cable. Here the communication nodes would act as repeaters, boosting the signal in regular intervals to prevent it from degrading. Importantly, Fink pointed out, the nodes have the capabilities to gather data themselves—for example measuring pressure, salinity, temperature and other chemical and physical parameters—and to ingest the data into the cable connecting back to the lander.

"Imagine you make it all the way to Europa, you melt your way through miles of ice, make it down to the subsurface ocean, where you find yourself surrounded by alien life, but you have no way of getting data back to the surface," he said. "That's the scenario we need to avoid."

Having developed the rovers and the communication technology, Fink's group is now working on building the actual mechanism by which the rovers would deploy the communication nodes.

"Basically, we're going to teach our 'Hansels' and 'Gretels' how to drop the breadcrumbs so they add up to a functioning mesh communication network," Fink said.

More information: Wolfgang Fink et al, A Hansel & Gretel Breadcrumb-Style Dynamically Deployed Communication Network Paradigm using Mesh Topology for Planetary Subsurface Exploration, *Advances in Space Research* (2023). DOI: 10.1016/j.asr.2023.02.012

Provided by University of Arizona