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Into the deep: Robots explore Earth's hidden depths

An intelligent, unmanned submarine is exploring Earth's most inhospitable places. Next stop: Jupiter's moons. Danny Bradbury reports on the potholers' project that's taking Nasa to the outer limits

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What do potholing, the moons of Jupiter and robots have in common? Very little at the moment. But a high-tech, unmanned submarine is changing that. So far, it's been exploring some of the deepest, most inhospitable potholes on Earth. In the future, it could be doing exactly the same thing - in space.

Next month, an "autonomous explorer robot" (AER) named DepthX will face its biggest challenge. The US team behind the AER proved the machine's worth in February when they sent it to the bottom of a well-charted sinkhole in Mexico. With DepthX still in test mode, they attached a fibreoptic cable to the robot, so they could see what it was doing in the deep, water-filled hole.

In the next few weeks, researchers will send it to the bottom of El Zacatón, in the Mexican state of Tamaulipas. No one knows how deep this mysterious hole is; divers got down to 282 metres and gave up. DepthX will travel through the underground world - untethered, this time - mapping its own route, navigating its own path, dropping a cluster of sensors on a wire to measure the lake at different depths, and taking samples of the water and rock. Its cameras will pick up visual information, creating three-dimensional images of El Zacatón.

But that's just the starting point. The word that makes DepthX special is "autonomous". The robot is designed to operate under its own steam, making decisions for itself without the help of researchers. It is already going where no one has gone before on this planet, but this autonomy will become even more important when robots are sent to explore other worlds.

The long distances involved in space travel make it difficult to guide a robot based on what it tells people about its environment. "Mars is fairly close to Earth right now, but one-way communication still takes 20 minutes," says Wolfgang Fink, head of the Visual and Autonomous Exploration Systems Research Laboratory at the California Institute of Technology (Caltech). "If you were to go to Titan [one of Saturn's moons], then you're dealing with over an hour." Nasa scientists spend painstaking hours instructing guided explorers, but building a robot that can guide itself is the next logical step.

In the meantime, while galactic plans are hatched, a mission to Antarctica's Lake Bonney is another good example of why autonomy is important. If a Nasa-funded project called Endurance gets approval from the National Science Foundation in Virginia, DepthX will descend into Lake Bonney in November 2008. The 130ft-deep lake - two and a half miles long by a mile wide - is trapped under 15 feet of ice, explains Peter Doran, an associate professor at the University of Illinois at Chicago. Controlling the robot conventionally on that mission could take an awfully long cable.

"We know a lot about the lake in the centre, but we don't know about things out toward the edge - not in three dimensions," says Doran. If successful, Endurance could be a precursor to another, larger project. Lake Vostok, also in Antarctica, is the size of Canada's Lake Ontario, and a likely destination for autonomous exploration. Some of the water there hasn't contacted the Earth's atmosphere in more than a million years.

Subterranean lakes in the world's most inhospitable places may not be too dissimilar from the lakes underneath Europa, Jupiter's fourth-largest moon. Astronomers believe that the ice-covered moon may harbour a layer of water under its surface. This would make it the only place in the solar system, other than Earth, with significant quantities of water.

The DepthX hardware was developed by Stone Aerospace, a specialist expedition-equipment company based in Texas. The firm approached Nasa to fund the initiative. "What we're looking at are concepts that could help us learn about how to do this kind of work on another world," explains John Rummel, senior scientist for astrobiology at Nasa, which has invested around $5m (£2.5m) in the scheme.

DepthX is too large to launch into space, explains Rummel. It's also too large for Lake Vostok, which is buried under two and an half miles of ice, because researchers would only be able to drill a hole much smaller than the 2.5 metre-diameter DepthX. Nevertheless, the hardware concepts demonstrated by the robot are just as valuable as the software used to control the vehicle, developed by researchers at Carnegie Mellon University in Pittsburgh.

Nathaniel Fairfield, a PhD student at its Robotics Institute, who helped to develop the robot's simultaneous localisation and mapping software, faced significant challenges in its design. Getting a land-based robot to navigate along a surface is difficult enough, but creating software to map a 3D environment, often in dark or murky waters, is an order of magnitude more difficult.

Robotic navigation is typically done using two techniques: dead reckoning and mapping. Robots use dead reckoning to work out where they are by remembering their movements, but this isn't always accurate. A robot might be told to travel 10 feet ahead but slipping wheels may mean that it only moves nine, and might move at a slight angle. This is a particular problem in water, where robots can drift. Multiply those inaccuracies by many movements over long distances, and the robot could get lost.

Mapping also has its problems - it works well if your map is clear and accurate but DepthX will be charting new territory. Consequently, such autonomous explorers can never be sure of their exact location or their surroundings. "If you don't know where you are, and you don't have a map, you're up a creek," says Fairfield.

DepthX uses these two navigation techniques together. It feels its way around using sonar, which gives it only sparse data about a complicated environment. "You take this chaotic, noisy, lousy data and you throw it into the map over and over, and eventually a clear picture emerges," explains Fairfield.

Using this data, along with dead reckoning, the robot creates a variety of hypotheses about the environment and its location. It keeps large numbers of them in its memory, refining them as it collects more data and building up a more accurate picture of its surroundings.

But it isn't enough for an autonomous explorer to know where it is; it has to know where it wants to go. Generally, researchers want to explore abnormal parts of the environment, such as rocks that are made of different material or surfaces that look different to others. To date, DepthX's researchers have done that manually, giving the robot a series of pre-defined waypoints to travel to and collect samples from. In the El Zacatón test, the robot will hopefully begin using its own maps to find interesting areas of the sinkhole's side and decide for itself what to investigate. "Technologically, the distance from these breakthroughs to creating a robot on Europa that can decide where to go, what to do and how to collect its data is a large one," Fairfield concedes.

At Caltech, Fink expects this to be one of the toughest challenges. Traditional artificial-intelligence techniques, which use lots of pre-programmed rules to help guide a robot, won't work here. "What if you encounter a situation that you haven't anticipated?" he asks. "Something for which you haven't put a rule in your system?"

Robots working on other planets must also learn how to fix themselves. DepthX is designed so that it could continue to swim, even if three of its six thrusters failed.

Keeping upright when an engine gives out may be pretty basic, but it's one of the things researchers must learn how to do right before they send truly autonomous robots into outer space. In order to explore far-flung planets, they have to plumb the depths of our own first.

Robot explorers in space

* MARS ROVERS

All of the planetary spacecraft at Nasa's Jet Propulsion Laboratory are semi-autonomous, say its researchers. The machines may not be able to work completely alone but they are good at navigating on their own. For example, the Mars Pathfinder rovers used stereo cameras to map the surrounding terrain and identify the safest route to their destination.

* INTERPLANETARY GLOBAL NAVIGATION SATELLITE SYSTEMS

Global positioning systems have made it easier to find our way around here on Earth, and the European Space Agency has proposed a similar system for other planets. Putting a ring of satellites around a planet like Mars could help explorers find their way around the planet by giving them an independent reference point in the sky.

www.esa.int/esaMI/Aurora/SEMYU7A5QCE_0.html

* AUTONOMOUS NANOTECHNOLOGY SWARMS (Ants)

Instead of one complicated robot, Nasa has proposed lots of tiny ones, which may roam around independently or be connected to each other. Each unit would be autonomous but would be linked to the whole community, enabling the Ants to act like a swarm of insects. The cost per unit would be low, andlosing one or two of them wouldn't endanger the mission. **ants.gsfc.nasa.gov/**

* TIER-SCALABLE RECONNAISSANCE

Caltech scientists have proposed exploration systems that use orbiting satellites to direct blimps floating in the atmosphere of suitable planets, like Mars. The blimps would then direct groups of exploration vehicles on the planet. Having an eye in the sky able to monitor the ground would enable explorers to be guided in groups.
autonomy.caltech.edu/autonomy/tierscalable.html