Team designs robots to help with human habitation in space

February 1 2024, by Leah Burrows

The gripper switches between three modes, which are suited to tasks that require maintaining a secure hold on an object or applying high pressure, precise finger positioning or in-hand manipulation, and passive adaptation to the shape of larger, delicate, or irregularly shaped objects. Credit: Harvard SEAS

In the coming decades, NASA plans to send human crews back to the moon, build a space station in lunar orbit, establish a permanent base on the lunar surface, and—hopefully—send astronauts to Mars.

What could possibly go wrong?

No, seriously, what could go wrong and how would we fix it? That is the question a group of researchers at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) have been asking over the past four years as a part of a research institute to develop resilient and autonomous deep space and extraterrestrial habitations.

The Resilient ExtraTerrestrial Habitats institute (RETHi) is led by Purdue University, in partnership with SEAS, the University of Connecticut and the University of Texas at San Antonio. Its goal is to "design and operate resilient deep space habitats that can adapt, absorb and rapidly recover from expected and unexpected disruptions."

Justin Werfel, Senior Research Fellow in Robotics at SEAS, is leading the team tasked with developing technologies to let autonomous robots repair or replace damaged components in a habitat.

"What happens if a meteorite breaches the habitat between missions, and the crew isn't there to fix it," asked Werfel. "Or if it happens during a crewed time, the astronauts may have their hands full with other emergencies. Likewise in more routine situations; there are a lot of regular maintenance tasks that take up valuable astronaut time, from replacing filters to cleaning things. You'd really like the habitat to be able to handle as much as possible on its own, which means robots doing that work."

Since the project began in 2019, Werfel and the team, which includes Robert Wood, the Harry Lewis and Marlyn McGrath Professor of Engineering and Applied Sciences at SEAS, have developed new robotic arms and grippers, new systems to improve human-robot collaboration and new ways to design robot-friendly equipment.

Multifunctional tools

One of the biggest challenges in designing robots for these so-called SmartHabs is the multifunctionality needed for deep space habitation. Most industrial robots, such as those used to build cars or stock warehouses, are highly specialized and perform only a few specific tasks

. But deep space habitats won't have room for dozens of specialized robots. Instead, one or a few multifunctional robots will need to be able to perform many different tasks, including emergency repairs.

One project toward that end has been to develop multi-mode grippers that can change their shape to grasp different types of objects in different ways.

"Human hands can adapt to many functions, including those that need high precision, require high forces, or those that may benefit from compliance," said Wood. "This design attempts to capture analogous adaptable behavior to increase the range of tasks possible with a single gripper."

In a paper published in *IEEE*, Werfel and the team, which includes collaborators from the Harvard Graduate School of Design (HGSD) and Pusan National University in South Korea, developed a gripper with fingers made of so-called scissor links, which can be reconfigured to change the number of joints in the finger.

This gripper has three modes. In the first, the fingers are short and don't bend, allowing them to strongly and securely grasp objects. In the second mode, the fingers gain a joint to let the gripper perform in-hand manipulation, allowing it to move and rotate objects without letting go of them. The last mode adds two more joints, allowing the fingers to passively adapt to the shape of an object and distribute contact pressure, which is useful for grasping irregularly shaped or delicate objects.

This paper was co-authored by Junghan Kwon, of Pusan National University; SEAS graduate students David Bombara and Clark Teeple; Joonhaeng Lee and Chuck Hoberman of HGSD; and Wood.

Working in a tight space

The first SmartHabs will likely be no larger than a mobile home and packed to the brim with equipment. Soft robots can be safer to operate around humans than traditional rigid ones, and could deform to more easily squeeze into tight spaces, but the softness also means they lack the strength they might need for some of the work they're called on to do.

To tackle that challenge, RETHi's robotics team designed a soft robotic arm that can stiffen up to increase its force and payload capacity.

The research was published in *Science Robotics*.

The all-SEAS team, which included Wood, Teeple, former undergraduate and postdoctoral fellow at SEAS Daniel Bruder, and graduate student Moritz Graule, designed a soft arm with two individually controlled segments.

Each segment consists of soft joints, which individually have only a small range of motion, but together can bend the arm 90 degrees. A few actuators placed along the spine and the joints can induce localized body stiffening, which allows the arm to pick up or move a heavy object.

"This design approach could lead to much more capable soft robot arms that can navigate the obstacle-rich environments of deep space habitats while safely interacting with human crew members and delicate objects," said Bruder.

Some tasks will require cooperative effort, like moving large or heavy equipment such as solar panels and satellite dishes. To let astronauts easily get help from robots on those tasks, Werfel and Nicole Carey, a former postdoctoral fellow at SEAS, designed a way for autonomous robots to follow human guidance without needing to know about the details of the task or goal, simply by sensing force applied to an object.

For example, if an astronaut needed help moving a solar panel, they could put their hand on the panel and guide the robots in the right direction, without explicitly needing to tell the robots about their intent.

"In this case, the shared object being manipulated acts as a physical channel for coordination," said Carey. "The human leader can apply a force and the robots follow that as a signal."

A robot-friendly habitat

Robots that can handle tasks designed for humans is one of the long-term goals of robotics—but it will take a long time and a lot of work to achieve it. Is there a way to let current robots help out sooner, by designing equipment with robots in mind?

That is another avenue being explored by Werfel and the RETHi robotics team.

"Instead of bringing the robot up to the level of the human, we're looking at bringing tasks down to the level of the robot, and building something that both robots and humans can easily operate," said Werfel.

In a 2022 paper, Werfel, Teeple and Nathan Melenbrink, a former postdoctoral fellow at SEAS, laid out strategies for designing robot-friendly hardware, including consolidating compound actions into simpler mechanisms and constraining required motions to a single axis.

The team redesigned several pieces of important equipment, including a water filtration component, to make them easier for robots to repair.

"Similar to the ergonomics design approach for humans, our robot factors design approach takes into account current robot capabilities during the design process," said Melenbrink. "We took hardware that previously required dexterous two-handed manipulation, and redesigned it so that the entire task can be completed by a single robotic arm with a standard parallel-jaw gripper."

As RETHi enters the last year of its grant, the SEAS robotics team will put their technologies to the test, in a combined physical and virtual simulation of the scenario of patching a hole left by a meteorite impact.

"Everything RETHi is doing is about creating tools for future habitat designers," said Werfel. "The goal is to give them more options for what their systems can handle, better predictions of costs when things do go wrong in systems of highly interconnected components with complex dependencies, and a greater capacity to design habitats that can handle whatever luck throws at them. It's not going to be possible for missions to avoid problems altogether, so it'll be the ability for our technology to deal with issues as they arise that will make human travel into deep space a reality."

More information: Junghan Kwon et al, Transformable Linkage-Based Gripper for Multi-Mode Grasping and Manipulation, *IEEE Robotics and Automation Letters* (2023). DOI: 10.1109/LRA.2023.3329758

Provided by Harvard John A. Paulson School of Engineering and Applied Sciences