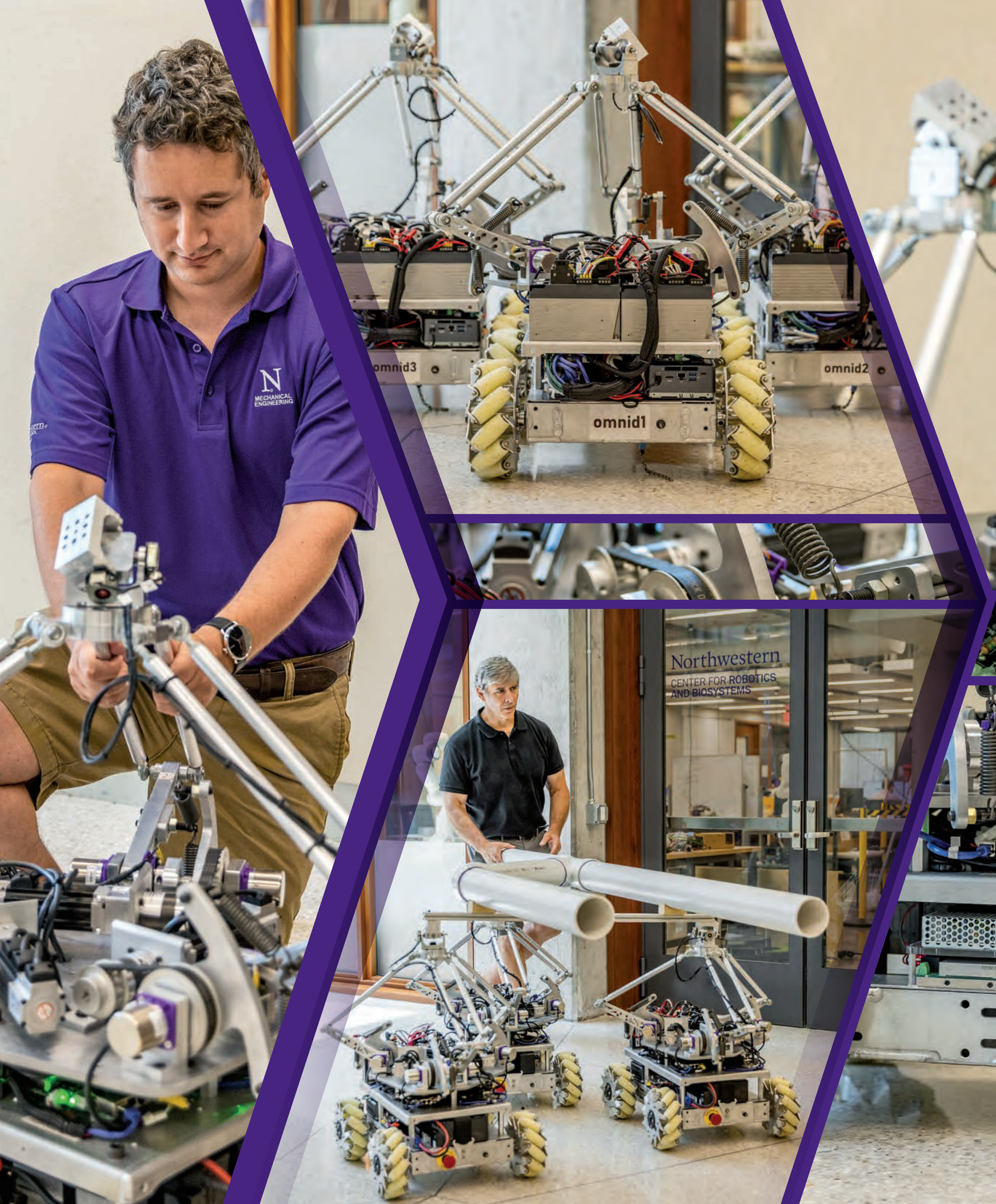
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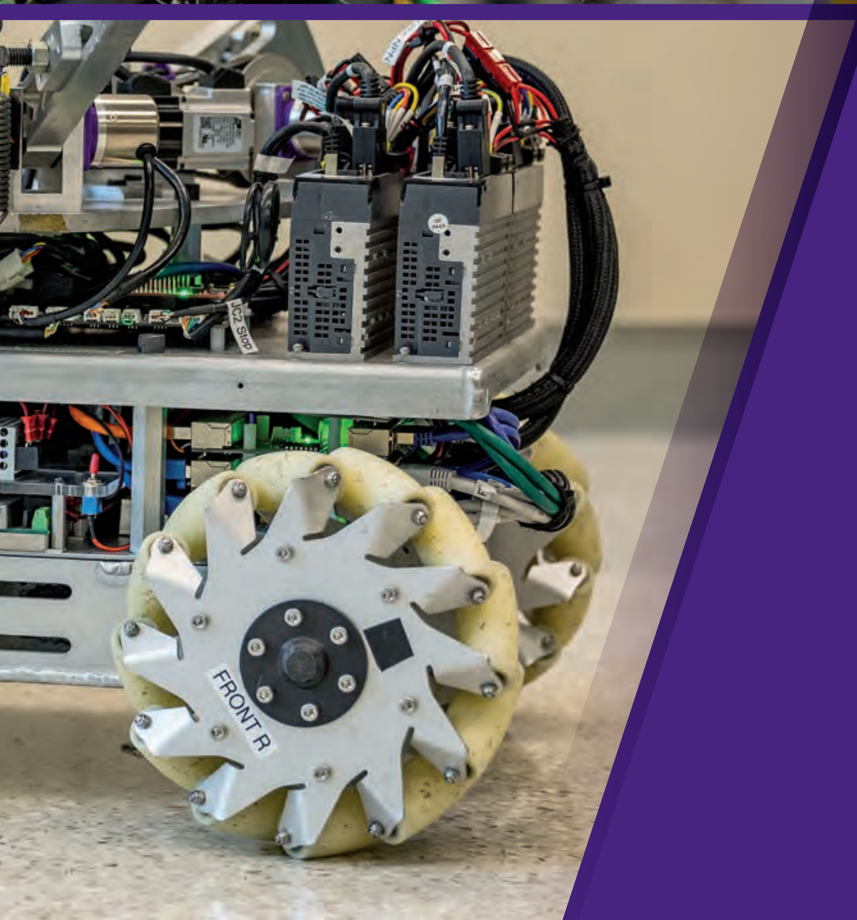


The Future of Human-Robot Interaction is Mobile

More than 25 years after Northwestern Engineering researchers advanced the concept of collaborative robotics, researchers in the Center for Robotics and Biosystems have designed team-based, mobile "mocobots" that could signal a new era of human-robot interaction in construction, manufacturing, and space exploration.

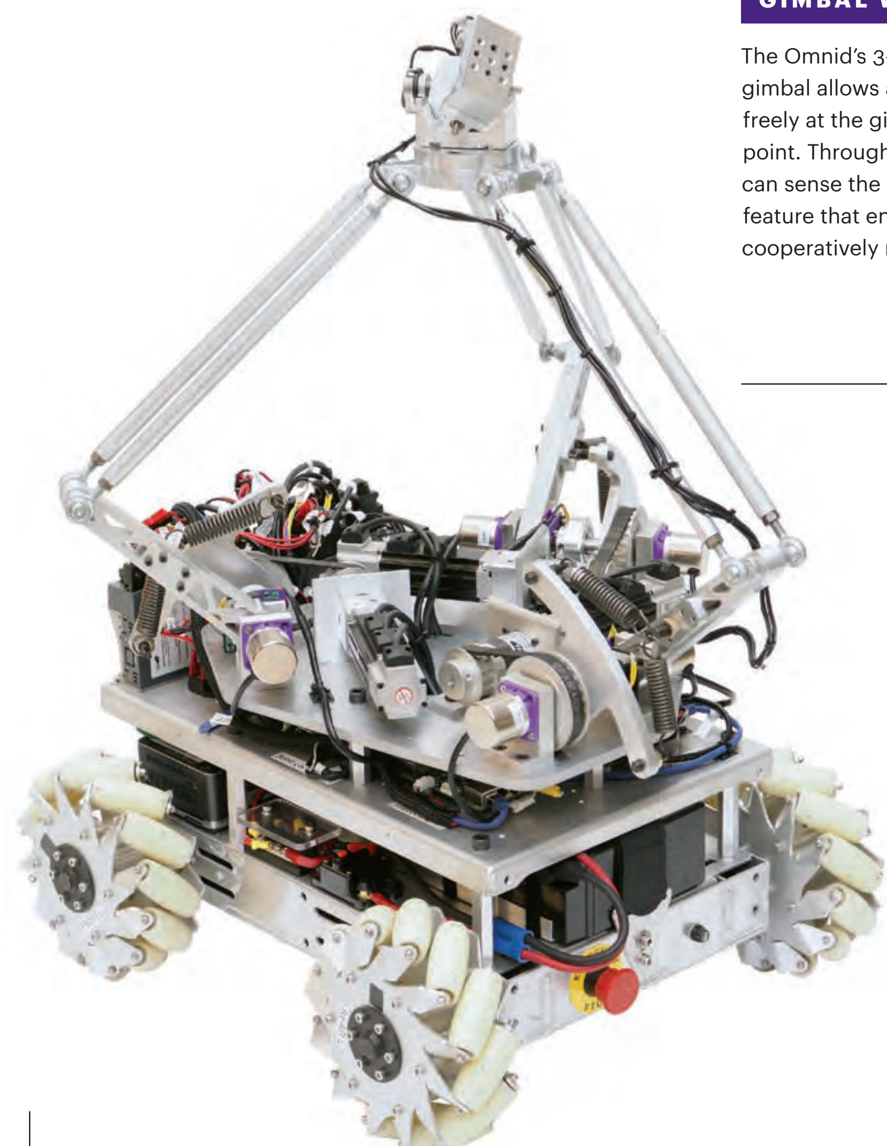
Standing alone in the atrium outside Northwestern's Center for Robotics and Biosystems, research engineer Billie Strong single-handedly performs, in a matter of seconds, a task that under other circumstances would require at least two people considerably longer to complete.

Positioned several feet from the action and using only one hand, Strong effortlessly and precisely inserts a 15-kilogram, two-pronged PVC pipe assembly into two circular openings in a wooden structure with just two millimeters of spatial tolerance in each hole. Strong then removes the eight-foot-long pipe from the structure, rotates it 180 degrees, and reinserts it from the opposite end.

Strong makes no claim of great personal strength or extraordinary precision. Three omnidirectional mobile robots perform the heavy lifting and stabilization while Strong gently guides the pipe assembly into place.

Kevin Lynch, professor of mechanical engineering at the McCormick School of Engineering, explains. "Physical collaboration with these robots is completely intuitive and requires no training for the human operator or reprogramming of the robots for this specific payload," he says. "That means the human can handle that 15-kilogram object with the feeling that it's floating in space."

The Omnid Mocobot



GIMBAL WRIST

The Omnid's 3-degree-of-freedom passive gimbal allows a human to rotate an object freely at the gimbal wrist's attachment point. Through this gimbal wrist, the Omnid can sense the angle of the payload, a key feature that enables multiple robots to cooperatively manipulate an object.

DELTA MANIPULATOR

The Omnid's Delta manipulator is a parallel mechanism that includes three identical arms that meet at the gimbal wrist. Each arm is driven by a series-elastic actuator. These springy actuators provide mechanical compliance that ensures the safety of the payload and collaborating humans. The actuators also enable high-fidelity force control—when multiple Omnids are used together, their manipulators nullify the payload's gravitational force, allowing users to manipulate heavy objects as if they are weightless.

MOBILE BASE

Four mecanum wheels—composed of small rollers around each wheel's circumference—allow the Omnids to travel omnidirectionally, including forward-backward motion, side-to-side motion, and rotation. This capability affords the human user complete freedom to transport a payload in tight spaces and perform precise assembly.

Watch the mocobots in action.

A legacy of human-robot collaboration

When Northwestern Engineering professors Ed Colgate and Michael Peshkin advanced the concept of collaborative robots, or "cobots," in the mid-1990s, they designed a single machine that could help automobile assembly line workers attach cumbersome parts, such as dashboards or side doors. The robot assumed the physical toil; the human maintained control and independence over the work.

Advancing the earlier concept, Lynch, director of the Center for Robotics and Biosystems, and a team of more than a dozen Northwestern Engineering faculty, master's, and undergraduate students have now introduced teams of "mocobots," mobile cobots that collaborate with each other and one or more human operators. Five years in the making, the new system expands opportunities for human-robot interaction in physically demanding environments—manufacturing plants, warehouses, construction zones, and the like—where teams of robots could help workers manipulate a variety of large, articulated, or flexible objects without placing physical demands on the human body.

Lynch reasons, "Instead of having a single, large robot that could manipulate anything you could ever want, why not have more, smaller robots that could easily adapt to the task at hand and possibly be less costly or space prohibitive? This is also particularly important if the payload is fragile, articulated, or flexible, and you need many distributed points of contact between the robots and the payload."

"Given Northwestern's leadership and history in the field," Lynch adds, "it felt natural for us to consider how to make humans and multiple robots work better together."

Built from scratch to be our partners

With robot manipulators and omnidirectional, mecanum-wheel mobile bases, the mocobot prototypes, dubbed Omnids, resemble other mobile robotic manipulators on the market today. Yet, these machines are custom designed for safe and effective collaboration within a team of robots and humans.

"Many existing mobile manipulators are designed to operate independently—a single robot manipulates a single object," says Matthew Elwin, assistant professor of instruction in mechanical engineering. "Some researchers have even experimented with small teams of such robots manipulating a common object. The problem is that these robots are not designed for safe human interaction, nor for safe cooperative manipulation of fragile objects. The robots overconstrain the object, and any errors in the robots' motion can result in large internal forces on the object."

The mocobot's differentiator is its built-in passive elasticity. Spring-loaded actuators within its 3-degree-of-freedom manipulator produce a springy response to different levels of force caused by the object's weight, forces from a human, or the robot's own movements. When coupled with the mobile base and a 3-degree-of-freedom passive gimbal wrist, the manipulator allows multiple mocobots to work cooperatively to render large objects weightless to the human collaborator.

"Given Northwestern's leadership and history in the field, it felt natural for us to consider how to make humans and multiple robots work better together."

KEVIN LYNCH Professor of Mechanical Engineering

"Where most robots are good at controlling their positions, our robots are good at controlling applied forces with passive elasticity for safety," Lynch says. "That passive elasticity kicks in right away to prevent objects from breaking, humans from getting hurt, or robots from being damaged."

Scaling up for the Red Planet

As described earlier, the team's first tests featured three mocobots collaborating with one or two human operators to install a PVC pipe and to transport and manipulate an articulated object—a 12-foot-long wooden assembly with a hinge joint. In the future, more mocobots could support more complex objectives and manipulation of flexible or articulated payloads with many degrees of freedom.

"We envision larger teams of even more powerful mocobots helping one or a few humans assemble large structures—a blade on a wind turbine, for example—in manufacturing and construction settings," Lynch says. "The system is designed to be scaled."

These robots' potential applications are not limited to Earth. As space travel could take humans to the moon and Mars in the coming decades, Lynch says mobile collaborative robots will play an important role.

"We'll need those robots to be able to work with humans on Mars right away, since we won't have automated factories there for a long time," Lynch says. "Mobile collaborative robots could help install solar panels on Martian habitats or build structures. While our prototypes are designed for indoor use, the principles of force control and passive elasticity in our mocobots could be applied to treaded or legged robots on rocky Martian terrain."

While mocobots are capable of autonomous manipulation using either preprogrammed controllers or strategies learned from their human collaborators, Lynch believes their flexibility to collaborate physically with people will be an enduring advantage.

"It's difficult to achieve complete robotic autonomy, and humans offer sensing, adaptability, situational awareness, and task understanding—qualities that are difficult to replicate," Lynch says. "The goal of our research is to take advantage of what the human does well while allowing the robots to do most of the work. The Omnids achieve that goal, allowing for mobile robot teams to collaborate safely and effectively with humans for the first time."

ALEX GERAGE

Photography by Matthew Allen