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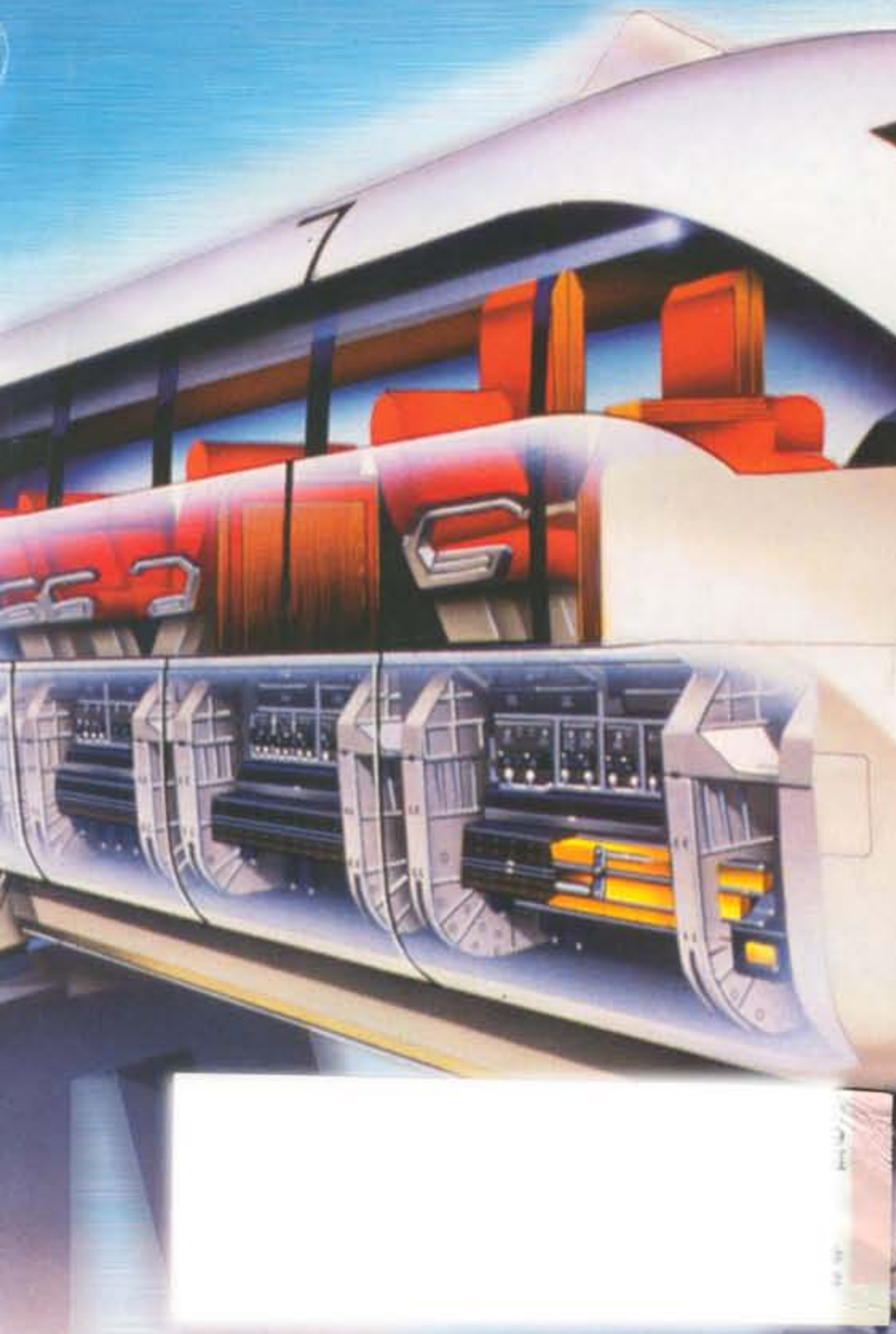

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SMART SHOVEL

A remote-control shovel lets its operator feel what's happening from miles away, making the removal of hazardous waste simpler and safer than ever before.

BY ROBERT LANGRETH

Perched in the middle of a radioactive waste site, the giant yellow machine looks like an ordinary hydraulic excavator, except there is no operator, or place for an operator. The only sign that humans might be watching are three cameras mounted on a platform above the engine.

Hundreds of yards away, the excavator's operator sits safely inside a building, observing the machine on several video screens. Rather than using complicated levers, he holds a handgrip that allows him to move the machine's arm with a natural digging motion.

At one point the operator feels resistance on the handle, although he can't see the cause yet on the monitors. He probes carefully with the shovel, literally feeling his way around the object, and soon uncovers a rusty barrel of radioactive sludge.

The unique machine is the Haz-Trak—probably the first intelligent machine in the traditionally low-tech world of construction equipment. Designed by Kansas-based Kraft TeleRobotics, this excavator and materials handler lets the operator control the mechanical arm as if it were an extension of his own and "feel" obstacles that the shovel hits.

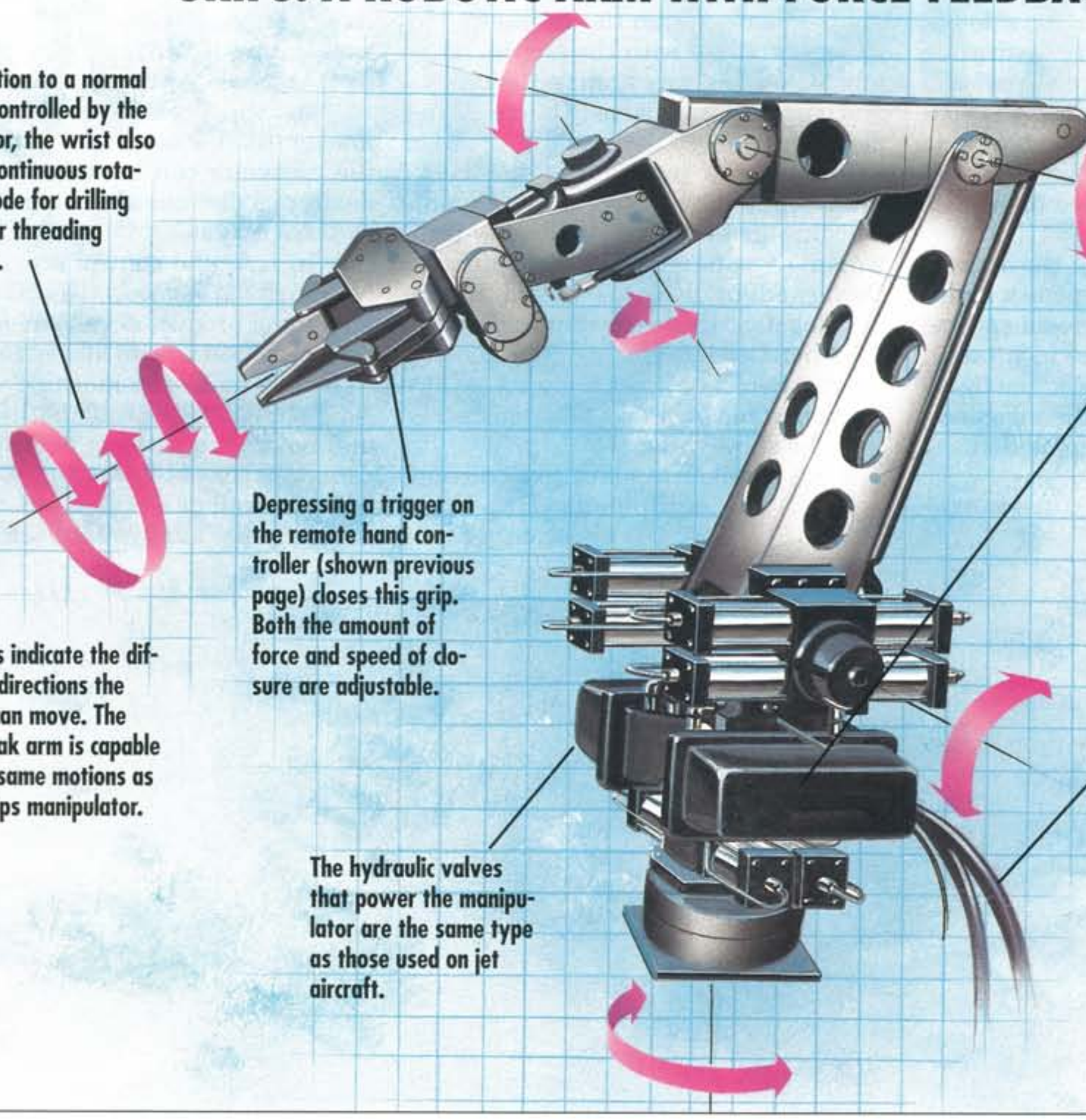
Unlike standard construction equipment, Haz-Trak takes only minutes to learn, the company says. With video screens providing left, right, and center views, a joystick for moving the tractor, and a handgrip allowing intuitive control of the mechanical arm, this machine is said to be easier to master than some video games. And the excavator can be controlled by radio from a distance that is limited only by the speed of light. "You could be sitting in L.A. and control a machine in New York," says Steve Harbur, Kraft's director of product development.

The advantage of these features is that they make the machine virtually "idiot-proof," allowing both experts and novices to perform delicate applications, such as troweling along the side of a wall or working around pipes or tree roots. In contrast, standard ex-

ILLUSTRATIONS BY JOE LAPINSKI

A safe distance away from the waste site, an operator watches the scene from three perspectives on video monitors. He moves the vehicle with the joystick, while controlling the vehicle's arm with the handgrip.

GRIPS: A ROBOTIC ARM WITH FORCE-FEEDBACK



cavators require several separate levers for control and take hundreds of hours to learn.

"Most remote control technology is clumsy, difficult to handle, and makes it easy to damage things," says Harbur.

If it catches on, Kraft's excavator could have a host of applications. As its name suggests, the tractor-propelled vehicle could prove useful for cleaning up hazardous chemical and radioactive wastes at weapons labs or Super Fund sites or removing unexploded munitions buried at military installations. Not only would it allow the operator to work at a safe distance, but he could also probe for buried waste without accidentally puncturing a barrel and releasing radiation or toxic chemicals.

"It would be a pretty handy tool," says an official at one weapons lab who is familiar with the Haz-Trak.

And that's just the beginning, says Harbur. For instance, someday, instead of hiring a contractor to dig a hole for a pool, homeowners may rent a version of Haz-Trak to do the job themselves.

Despite its promise, Kraft's vehicle remains unproven; while the company has built a prototype, it has only demonstrated a scale model of the technology to potential customers and is still waiting for its first order. Also, it's unclear whether the tool will be adopted by an industry that hasn't changed significantly in decades.

But Harbur, an engineer turned salesman, isn't phased by the challenge. "Because it's such a dramatically better man/machine interface, it opens up a whole new design path."

To test Kraft's claims, I visited the company's small facility on the outskirts of Kansas City. Harbur and Brett Kraft, the company's founder and president, showed me around. The first stop was a demonstration of the Grips manipulator—a $4^{1}/_{2}$-foot-long remote-control robotic arm, upon which the Haz-Trak is based. In production for three years, it has been used by NASA for space station research and development, in the nuclear reactor cleanup at Three Mile Island in Pennsylvania, and even by a team of divers searching for sunken treasure. Another coup was licensing the technology to a Japanese manufacturer that has developed a new kind of power-line repair truck. Operators sit safely inside a closed cab atop a 45-foot telescoping boom, while two Grips arms in front of the cabin handle high-voltage lines and other hazards.

The only difference between Grips and Haz-Trak is scale, Harbur explained to me as we strolled up to the machine. "Haz-Trak is basically a giant Grips manipulator."

What makes the robotic arm so easy to use is a combination of force-feedback and master-slave control, he continued. Master-slave control simply means that as you move a handle in a certain way, the robotic arm performs exactly the same motion, like a puppet obeying a puppeteer.

Force-feedback refers to the fact that a portion of the resistance the machine encounters is converted into resistance that the controller feels. Suppose the arm hits a piece of wood underground. The wood exerts a force felt by hydraulic actuators in the arm, which is changed into a radio signal and sent back to the controller. Then electronic

[*Continued on page 108*]

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Smart shovel

[*Continued from page 84*]

actuators in the handgrip convert the signal into resistance that the operator feels—albeit at a lower, more manageable level.

Two technologies in one

Neither force-feedback nor master-slave control are new ideas. Simple force-feedback devices have been used for decades in nuclear power plants, and construction equipment companies have toyed with master-slave controls in the past. But Kraft is the first to unite the two technologies in an excavator vehicle.

"Master-slave control doesn't work well without force-feedback," Kraft told me. "If the tool encounters resistance and falls behind your arm, it struggles with all its force to catch up" —even though you may not be pushing hard at all. If you are handling radioactive sludge, this could be dangerous. However, with force-feedback, your arm stays in sync with the robot.

At first I tried the robotic arm with the force-feedback on. Sitting in a chair, I moved a handgrip conveniently positioned a foot above my lap. Ten feet away the manipulator arm, connected to the control apparatus only by radio, followed my motions.

As promised, it took me almost no time to learn: If I moved my arm left, the machine's arm moved left; if I moved right, it moved right; if I made a digging motion, it made a digging motion. By attaching a bucket to the end of the robotic arm, I started to dig a hole in a sandbox. Each time the bucket hit the sand, I felt a slight resistance on the handle. At one point, I suddenly felt a much greater resistance. Sure enough, I saw that I had hit the side of the sandbox.

By pressing a few keys on a pad the size of a TV remote control, Kraft showed me how to adjust the distance the machine moves relative to my motions. For example, to make the machine very sensitive, he set the remote so that the arm turned one degree for every ten degrees I turned the handle. This let me slowly maneuver the robot's grip around an empty soda can; by pressing a button on the side of the handle with my thumb, I tried to grab the can. The first time I quivered too much and missed, but the second time I got the arm in the right place. Even though the grip can squeeze with up to 250 pounds of force, by pressing lightly on the button it closed without crushing the can.

Next the force-feedback was turned off. At first, the difference was subtle. The arm still worked intuitively, and digging wasn't more difficult. Then I

swung the shovel hard into the sand along the edge of the box. Straining to catch up with my movement, the bucket snagged along the side of the box, then suddenly came free—coming close to spilling its load of sand on Kraft.

"See what we mean?" Kraft asked. Score one for force-feedback.

The second stop was the prototype Haz-Trak. Despite its high-tech innards, the vehicle sitting in Kraft's warehouse looked ordinary on the outside—in fact, to save money the company created it from a store-bought excavator. The only visible differences between it and any other piece of construction equipment was the camera (only one was installed at the time), the lack of a cab for the operator, and an extra joint in its arm that gives it more degrees of freedom than conventional equipment.

When it rolls out its first production model in the upcoming months, Kraft plans to fit its excavator with the same long list of technological goodies as its Grips manipulator. Among others, the end of the arm will fit a variety of tools, from a shovel to a barrel handler. Operators will be able to "record" previous movements and have Haz-Trak repeat them on command, making it easier to perform repetitive tasks that require precise control. To avoid accidentally hitting walls or other obstacles, operators will be able to program limits to the arm's motion. And they will be able to adjust the amount of force-feedback. A novice operator may want to feel one pound of resistance for every 100 pounds that the excavator encounters; an experienced user who needs to work for long periods without tiring may want much less.

"This product is a very interesting solution to the basic problem" of finding an intuitive way to control heavy construction equipment, says Carl Bohman, an independent consultant for several construction equipment companies. "I'm surprised some of the backhoe excavator companies haven't picked up on it."

Future applications

In the near term, Kraft is focusing on attracting customers in waste cleanup or weapons removal. The largest potential customer is the U.S. Department of Energy, which plans to spend $5.3 billion next year to clean up waste at nuclear weapons laboratories and plants scattered across the United States.

Although it will take time to penetrate the government bureaucracy, Kraft thinks that the prospects are good and hopes to wrap up its first sale in the next few months. Two Department of Energy laboratory officials who are familiar with the vehicle agree. "I'm excited about the possibility of this technology helping us remediate dangerous wastes," says one official.

In the long term, Kraft would like to produce an excavator for everyday applications. The main obstacle is convincing an industry accustomed to the status quo to invest in an untried technology. "If we get one company to go with this . . . others will follow," Harbur says. "It's finding that first one that's hard."

While it waits for an order, Kraft is gearing up to produce eight vehicles. If they sell, it just may mark the entry of construction equipment into the technology age. PS

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