NANOMACHINES

NanoManipulator Lets Chemists Go Mano a Mano With Molecules

Interacting with the nanoworld is like shadowboxing in the dark. Because objects only a few molecules across are too small to be seen or touched directly, scientists approach them essentially blind and numb. Now a team of physicists, chemists, biologists, and computer scientists at the University of North Carolina (UNC), Chapel Hill, has developed a tool that restores their eyes and fingers. It's called the nanoManipulator.

"It is like the movie *Honey, I Shrunk the Kids,* except you don't really get smaller," says UNC computer scientist Warren Robinett. "We reconstruct your perception so that you see and feel exactly what you would if you were the size of a virus." Robinett created the nanoManipulator with chemist Stan Williams, who is now the director of basic research in the physical sciences at Hewlett-Packard. The device "puts humans in the loop in a very nice way," says Ari Requicha, an electrical engineer who works on virtual reality interfaces at the University of Southern California in Los Angeles.

Robinett and Williams, who have been friends since their undergraduate days in the early 1970s, came up with the idea for the nanoManipulator during a 1991 phone call. At the time, Williams was trying to string single silicon atoms into a nanoscale wire, but he was frustrated by his inability to touch the atoms. "Chemists want to get their hands on stuff," he says. For his part, Robinett was looking for a safer application of his expertise in programming people-sized robots that mimic the motions of their human operator. When working with big machines, Robinett explains, "a bug in your program can turn a robot into an eggbeater, and it can punch a hole in your skull."

Tiny fingers. Postdoc Martin Guthold uses the nanoManipulator to probe carbon nanotubes.

To Robinett, the scanning probe microscope (SPM) that Williams used to view his surfaces looked like a small and safe robot. Instead of the robot's TV camera eyes, the SPM has a computer-controlled probe that "looks like an upside-down pyramid at the end of a flexible diving board," says UNC computer scientist Russell Taylor. The probe skates across the silicon surface, and a computer interface converts the probe's wiggles into an electric signal, a bit like the way a phonograph needle creates sounds from the bumps in a vinyl record.

The probe can also be programmed to push against the surface like a robotic finger. In the push mode, scanning tunneling microscopes (STMs) are commonly used to photograph products of chemical reactions, measure the mechanical properties of various materials, and rearrange atoms and bend carbon nanotubes. But there's a problem. To point the tip in the correct direction, researchers first scan the surface and find the target in the resulting three-dimensional (3D) image. Then, they must switch from visualization mode to manipulation mode, program the STM tip to move to the right spot, and finally press it against the surface. In the meantime, thermal vibrations of the surface might have bounced the atom away from the tip's preprogrammed target. It is like trying to play blindfolded billiards during an earthquake.

But even in the push mode, the changing separation between the flexing tip and its fixed mount creates an electric current that is proportional to the pressure exerted on the tip. By transmitting that current to the proper computer interface, Robinett and Williams realized that a human could locate the target object by touch at the same time they were pushing gently against it. All Robinett had to do was revamp his human-sized robot control programs to link the microscopic "robot" to a human. And the nanoManipulator was born.

In its current form, the nanoManipulator is a computer program that fuses an STM with a real-time 3D graphics rendering program and a haptic interface that fits over one finger like a high-tech thimble. The scientist's fingertip gets a little push each time the probe hits a bump. And when the scientist pushes back with his finger, a nanoscale finger presses against the surface.

"The key to the manipulator is that it immerses users in the environment so they develop a good feel for what they are doing," says electrical engineer Joe Lyding, an expert in molecular computing and visualization at the University of Illinois, Urbana-Champaign. For example, a user can tell the difference between signal noise and real texture by simply running a "finger" over the surface, says Williams, who has also used the nanoManipulator to "nano-weld" atoms into a wire strand.

Garrett Matthews, a graduate student in physics at UNC, is using the nanoManipulator to figure out if a virus feels more like a cue ball, a tennis ball, or a rotten tomato. The results are inconclusive. "Right now it feels like a cue ball, but we have other measurements that indicate it should be soft and sticky," says Matthews. Versions of the nanoManipulator are also being used by chemists and materials scientists at Catholic University of Leuven in Belgium, the University of Toronto, the National Institute of Standards and Technology, and Arizona State University in Tempe.

Williams is not surprised at the device's increasing popularity. "We used to have to stare for hours at a black-and-white picture of a surface just to tell what was up and what was down," he says. "The nanoManipulator has untied our hands and opened our senses."

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wholly on the drawing board," John Seely Brown writes in a research paper submitted to the September NSF meeting. Brown, who heads the famed Xerox Palo Alto Research Center in California, points out that two of the main proponents of nanomachines, Ralph Merkle and K. Eric Drexler, built powerful nano-CAD tools and then ran simulations of the resulting designs. "The simulations showed definitively that nano devices are theoretically feasible," Brown writes. "But theoretically feasible and practically feasible are two different things. And as yet, no-one has laid out in any detail a route from lab-based simulation or the extremely elementary nanodevices that have been chemically constructed to practical development."

But others argue that visionary research serves a purpose, too. Even if nanogears and pistons cannot be built yet, says Deepak Srivastava, who heads the computer nanotechnology design group at NASA's Ames Research Center in Moffett Field, California, the computer designs still help focus experimentalists on what's worth looking for: "If the ideas are based on real

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