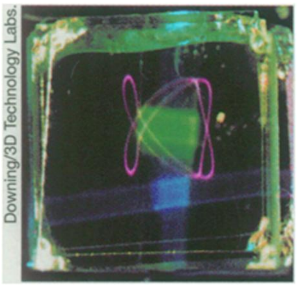
Sculptures of Light

A new three-dimensional display turns on the imagination

By CORINNA WU

There's something deeply satisfying about wresting a three-dimensional image from a two-dimensional picture. Witness the recent popularity of computer-generated "Magic Eye" art: Wherever one of these pictures hangs, throngs of people gather around to stare, squint, and cross their eyes in an attempt to make the concealed 3-D form leap out.

For those 3-D pictures, looking for the images is part of the fun. For 3-D techniques being developed for medical imaging, however, the fewer ocular and mental acrobatics required, the better. Existing approaches, such as computer images that can be rotated at will, work well in many cases, but they often give only a limited viewing angle or require clumsy headgear. Their fundamental drawback is that they are still essentially flat.



Downing/3D Technology Labs.

A red twisted loop and green and blue squares glow inside a 1.5 centimeter cube of fluoride glass.

Recently, a group of researchers took a major step toward true 3-D visualization. Elizabeth Downing of 3D Technology Laboratories in Mountain View, Calif., and her colleagues have designed a three-color, 3-D display that generates what appear to be solid objects rather than creating an optical illusion on a computer screen. They describe their creation in the Aug. 30 Science.

Though still a few years away from practical use, the invention created a flurry of excitement among scientists who foresee its potential applications. "It's an approach which is unique in what it can deliver and the way it goes about displaying information," says study coauthor Roger Macfarlane, a physicist at IBM Almaden Research Center in San Jose, Calif.

The device is the culmination of 8 years' work by Downing while studying mechanical engineering at Stanford University, and now she's determined to see her display through to the marketplace.

The prototype display consists of six small lasers aimed at a block of fluorescent fluoride glass about the size of a sugar cube. At points where the lasers intersect within the glass, the fluorescence they provoke traces out shapes and patterns. During one demonstration, a red loop and green and blue squares glow from the interior of the cube.

The ghostly, transparent images can be viewed from any angle, Downing says, which is an improvement on available imaging technologies. One, for example, renders 3-D objects on a computer screen through realistic lighting effects and shading. "It's very sophisticated and actually pretty good for most things," she says, but the illusion changes if a viewer's head moves. This problem of a restricted viewing angle also plagues other techniques, such as stereoscopic displays.

In principle, Downing's display works much like a television screen, which is coated with phosphorescent chemicals that glow when scanned by an electron beam. Downing sandwiched together three layers of glass to form the cube, each layer doped with a rare earth ion that provides one of three colors: red (praseodymium), green (erbium), or blue (thulium).

Each ion fluoresces only when excited by light of two different wavelengths, a process called upconversion. Two excitation photons are converted up to emit a single photon of combined energy, Macfarlane explains. One laser beam enters the sample and excites an ion to a higher energy level. When the other beam hits the ion, it gets kicked up to an even higher energy. Only then does the ion fluoresce, as it falls back to the ground state and emits light of a specific wavelength.

Moving the two beams traces out a 3-D shape, in the same way that twisting the two knobs of an Etch-A-Sketch toy draws an outline. The lasers redraw the image 30 to 100 times a second, a rate that refreshes the display fast enough for the eye to see a static figure. The spot, or voxel (from volume-pixel), where the lasers cross is only about 100 micrometers in diameter.

Downing assembled the display on a shoestring budget, spending a lot of time "begging for equipment and sometimes stealing it," she jokes. John Ralston of SDL Corp. in San Jose, also a coauthor of the Science article, gave her the lasers she needed. Macfarlane steered her toward the fluoride glass, which had been invented by French scientists Michel Poulain, Marceau Poulain, and Jacques Lucas.

Although she would have preferred buying it, she says, Downing ended up making the glass herself, experimenting with different proportions of ingredients to optimize the fluorescence.

Fine-tuning the fluorescence proved tricky. If the concentration of rare earth ions in the glass was too low, the material didn't glow enough. If the concentration was too high, the ions would reabsorb the emitted light, either quenching the fluorescence or causing the material to glow outside of the targeted voxels.

Downing likens the glass-making process to baking chocolate chip cookies. "If there aren't enough chips, the cookies don't taste good. But if there are too many, that doesn't work either."

One immediate goal of the researchers is to get erbium to do double duty by glowing both red and green. The fewer elements needed, the simpler the ultimate display design. In that scheme, as before, one laser would push erbium to the first energy level. The wavelength of the second laser excitation would determine the resulting color. "If you don't climb so high, you get red light. If you climb higher, you get green light," Macfarlane explains.

They need to fine-tune the excitation wavelength and perhaps tweak the composition of the glass to get the greatest efficiency for each color, Macfarlane says. Eventually, they will also have to increase the size of the glass block to make the technique practical.

Downing conceived of the idea for the 3-D display on June 21, 1988, according to an entry in her notebook. She later learned that similar work had been done nearly 20 years earlier. In the early 1970s, J.D. Lewis, C.M. Verber, and R.B. McGhee, then at Battelle Laboratories in Columbus, Ohio, used xenon lamps to excite an erbium-doped crystal but produced only a faint glow.

Downing's success became possible only through recent advances in laser technology and materials. The Battelle scientists were ahead of their time, she says.

When Downing started her project, the equipment available to her was barely adequate. Just 3 years ago, she and her colleagues had to rely on several pitifully inefficient, 5-foot-long lasers to stimulate the glass. Now, they use compact solid-state lasers similar to the ones found in compact disc players. These lasers can be bought in a wide range of wavelengths and give exceptionally good output. The prototype display fits on a 1-foot-square breadboard. "You can literally hold it in your hand," Macfarlane says.

Other scientists in the imaging field are impressed. Guy A. Marlor of West End Partners Imaging in Fremont, Calif., says he saw her demonstrate the system. "I was totally fascinated," he says.

The technology has caught the fancy of the medical imaging community because of its potential for displaying data from computerized tomography (CT) scans, ultrasound, and magnetic resonance images (MRI) in three dimensions. At present, these techniques, for all their detail, show only flat slices of very solid human bodies. Doctors must mentally reassemble the slices to get a coherent picture of the body part.

Though still a long way from being able to display that kind of information, the new technology may allow doctors to see, for example, heart valves working or blood flowing in the brain, Marlor says.

Many groups are now experimenting with ways of displaying reassembled data slices on a computer screen, but one of the 3-D methods that has already penetrated the medical imaging market is digital holography, developed by Voxel of Laguna Hills, Calif. Exposing holographic film to multiple CT, MRI, or ultrasound scans builds up a composite image. The resulting hologram—a floating "sculpture of light"—can be viewed through a special light box.

Surgeons can insert instruments into the hologram to gauge distances, and they can overlay holograms of different tissues—a network of blood vessels over a tumor, for example—to see how they relate. The technique can't portray movement within the body, however.

Digital holography is especially valuable for seeing abnormalities in the spine and the brain, says William Orrison, director of the New Mexico Institute of Neuroimaging in Albuquerque. After his first look at a hologram, he says, the 20 years he has spent studying neuroanatomy became instantly clear. "If a picture is worth a thousand words, then a hologram is worth a million," he says.

For the past 2 years, the institute has sent MRI and CT data to Voxel for processing. The first on-site camera, which can take and develop such digital holograms in less than half an hour, is scheduled to be installed there this month.

All 3-D technologies have their advantages and disadvantages, says Raymond A. Schulz, a spokesman for Voxel. Downing's technology is "done in a solid cube, so it's not a piece of film you can transport from one place to the other," he says. "You can't stick a surgical screw in it." But it has the potential to show motion where holography does not, he adds.

"She's got a lot of technical hurdles to overcome yet, but it's certainly very interesting."

The big limitation of using this technique for medical imaging, Downing and Macfarlane acknowledge, will be the time it takes to transfer the enormous amount of data contained in multiple scans to the display. "You know how long it takes to write graphics on a computer screen in 2-D," Macfarlane says. "There's an awful lot of picture elements involved when you add a third dimension." Data compression techniques and arrays of lasers, each responsible for scanning smaller areas of the glass, might reduce the burden.

Downing estimates that 3D Technology Laboratories is 4 or 5 years away from having a salable product. "Our goal is to push a new technology into the marketplace," she says. "We want this in hospitals, schools, anywhere it can help engineers solve problems."

For now, though, the next step is simply to get the device to produce more complicated figures: the Eiffel Tower, a jumping frog, and Herbie the Love Bug, to name a few on the drawing board.

Those further investigations are temporarily on hold, however. Downing has gotten so much interest in the technology that she has been spending most of her time on the phone talking to reporters and potential investors rather than in the lab. □

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column, according to Lawrence Mayer, a biogeochemist at the Darling Center.

Sediments supply about half of the nutrients in waters to depths of perhaps 200 meters, he notes. Studies have shown that a host of environmental factors can affect how bacteria manipulate chemicals in their vicinity. For instance, a sediment's geometry can influence whether bacteria release nitrogen in biologically useful forms that serve as natural fertilizers or in inactive compounds that most animals ignore.

"As we trawl," Mayer notes, "we convert the geometry of the ecosystem from one containing a small number of large burrows to one that contains a large number of small burrows." This reflects the replacement of larger animals by small opportunists.

Will trawling prompt sediments to act as a source or as a sink of fertilizer for continental shelf ecosystems? "I haven't the slightest idea," Mayer says. Too little research has been done on this "terribly complex system" to offer a useful gauge.

Today, fisheries are managed largely in terms of how many animals can be harvested without reducing the vitality of the population. The new trawling studies raise questions about the extent to which commercially fished stocks depend on habitats that are being degraded by seafloor trawling, Rosenberg says. He would like to see long-term monitoring of the ignored seabed communities to establish their role in the productivity of commercial fisheries.

Sidescan sonar image from Irish Sea depicts marks scored on seabed by passes of a 4-meter beam trawl.

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So would Norse. Unfortunately, he says, this topic "has gotten very little attention" to date and even less research funding. Nor should the economic performance of commercial fisheries necessarily be the primary focus of such research, he argues. He would like to see the conservation of biodiversity accorded equal importance.

Toward that end, he advocates the development of marine reserves closed to fishing and other human disturbances.

Gordon, Schwinghamer, and some of their colleagues would also like to see the use of mobile gear in fisheries managed more conservatively, arguing that trawls and dredges should be permitted only in certain regions and be used only during specified periods, depending on the apparent vulnerability of the habitat and its role in the life cycle of other fishes.

Rosenberg would take more of a wait-and-see approach. He says that telling people not to trawl "is not a particularly viable strategy." He would like to see other management options explored through research that looks not only at biology but also at the sociology and economics of fishing.

John Williamson, a fisherman from Kennebunk, Maine, who does not use bottom trawls, worries that the answers to such questions may come too late.

Not long ago, he could motor out to where huge schools of fish congregated and reliably haul in the day's limit. Today, he says, "I'm not going to find a large concentration of fish anywhere"—and the situation is only getting worse. Already, he charges, it's as if fishers have been reduced to hunting down "small patches of fish in the middle of a barren desert." □