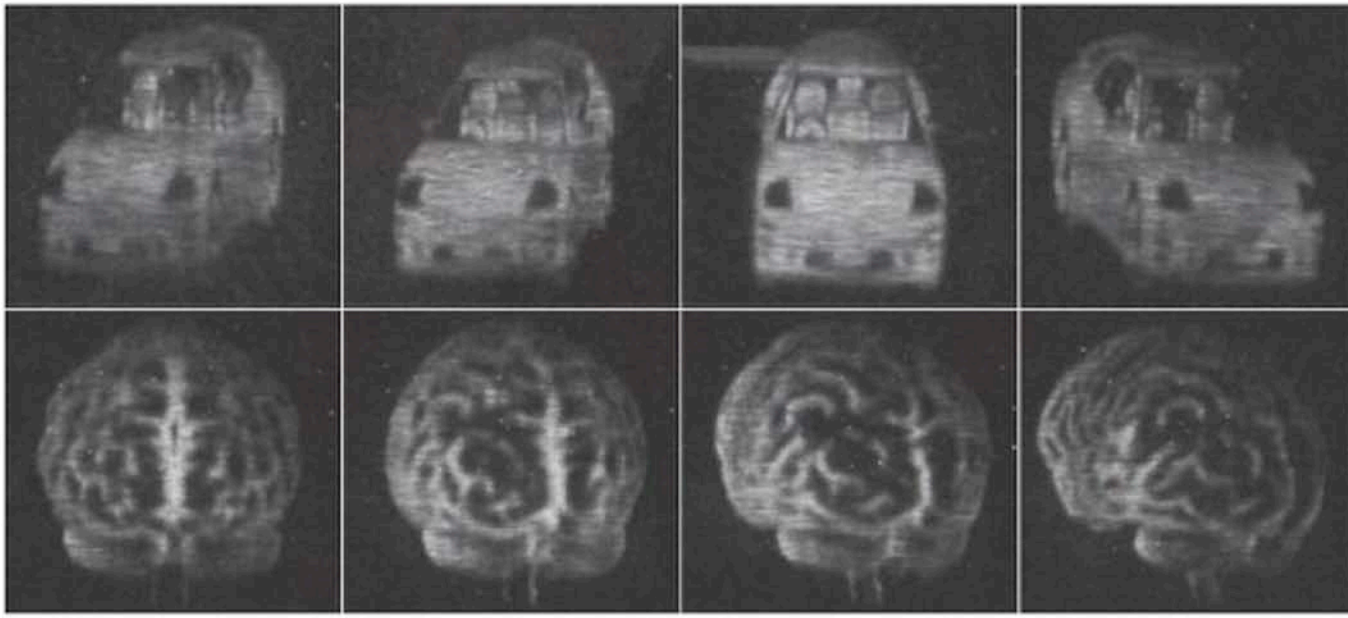
SIMULATED REALITY
The Science of Holograms

By Colleen Carlston



credit: Ref. 1.

▲ ABOVE: Holographic images of a toy car and a brain.

"The 3-D display can be recorded in 3 minutes and can be viewed for up to 3 hours without fading. We have reduced the writing time while maintaining hours of persistence." - Nasser Peyghambarian

"Help me, Obi-Wan Kenobi; you're my only hope." Thus ends Princess Leia's holographic plea. Let's face it; a reader of this publication is probably familiar with this scene from the first Star Wars movie, but what he may not know is that holographic video imaging, which until recently existed only in the realm of science fiction, is becoming reality thanks to the work of scientists at the University of Arizona(1). In the past, the major barrier to achieving an updatable 3-dimensional holographic display was that, once a hologram was created, it could not be erased to form the next frame in a movie image. However, for the first time this February the Peyghambarian group presented their invention of a 4 x 4 inch photorefractive 3-D holographic display that can be erased and updated with new images.

Perhaps this all seems like old hat. As any visitor to Disneyland or IMAX knows, 3-D video has been around for a while. However, these are not true holograms but rather, stereoscopic displays, in which two 2-D images separated by the average distance between human eyes are projected while viewers wear special glasses with one red lens and one blue lens(2). The brain is then responsible for merging these images to give the 2-D projections on the movie screen a combined 3-D appearance. Besides the obvious disadvantage of cumbersome glasses, stereoscopic displays also lack the realism of high-quality holograms.

Despite these shortcomings, stereoscopic displays do have a major advantage over the holographic display developed by the Peyghambarian group; they are capable of handling real-time video. To clarify, even video as we know it is not strictly real-time imaging but the projection of sequential still frames, which above a certain threshold of frames per second appears as continuous motion to the human eye. The same principle is in action with flip books. While there is still some debate over how many images per second the eye is capable of processing, roughly


credit: Adapted from Ref. 1.

▲ ABOVE: A hologram can be "erased" by exposing it to uniform light.

15 frames per second are needed for a video image to appear fluid. Until recently, all broadcast television in the United States used the analog National Television System Committee (NTSC) format of 30 interlaced frames per second (3). While the resolution of images captured by the new hologram system is nearly as sharp as that of those broadcast in the NTSC format, the time it takes for each new frame to be produced is significantly longer (4). The entire holographic process of sensing and recording an object, erasing the last image and projecting the next takes about 120 seconds (1).

Although the display cannot yet project real-time video, it is a vast improvement over the static holograms of the past and could have potential applications ranging from advertising to visualizing the inside of the brain during surgical procedures. The program was actually funded by the Air Force Office of Scientific Research to assist military command and control centers in modeling dynamic battlefield situations (5). Yet, the advantage to most people, other than how cool it would be to own a "holophone" someday, is that this technology could dramatically increase the capacity of computer memory by storing rewritable layers of data (6).

How holograms are "written" and "read" by lasers.

What exactly is a hologram, other than that shiny symbol on your credit card? A hologram is a piece of material that contains the optical information that would usually come from an actual 3-D object (7). This optical information is encoded into the hologram using two "writing beams" of laser light. A "reading beam" which can be either daylight or another laser is then used to produce the image of the original object. Static holograms show the highest resolution and are recorded by a laser making irreversible chemical changes to the material (6). However, static holograms have a limited parallax field, which means that they do not appear realistic when viewed from different angles or directions. Thus, one cannot walk around the image or have many people viewing it at once.

The material developed by the University of Arizona team in conjunction with Nitto Denko Technical Corporation in Oceanside, CA is based on a plastic used in optical communications systems. Although it is less than a millimeter thick, it is extremely responsive to lasers and can accurately reproduce colors (6). A phase hologram reproduces the interference pattern formed by combining two light fields. When light strikes the plastic, it absorbs photons and excites electrons in the material. These electrons leave behind positively charged "holes". A separation of charge takes place and small electric fields form as a result. This material also contains dye molecules that physically rotate in response to the electric fields. This rotation in turn affects the refraction index for light in different parts of the material. When a second laser is then focused on the material the dye will bend and reflect that light to project a pattern interpreted by the eye as the original 3-D image (8).

Following this process, the hologram can be "reset" by uniform light. A field of equally distributed radiance is commonly used for testing and calibrating everything from cameras for the consumer market to advanced scientific imaging devices (9). What uniform illumination at the writing wavelength does is that it redistributes the electrons and the holes, canceling the changes in refraction index that had been created by the mini electric fields. In the past, challenges presented by creating bright or enduring images hindered the development of updatable holograms. Fortunately, this new photorefractive material produces long-lasting high optical intensities and was created using common polymer processing techniques so that it can be scaled to larger sizes and separate panels can even be tiled together. (1) As Peyghambarian told New Scientist, "The 3D display can be recorded in 3 minutes and can be viewed for up to 3 hours without fading. We have reduced the writing time while maintaining hours of persistence (6)."

The current limitations to speed are a reflection of how quickly electrical fields can be established in the material, but there are no theoretical limits to achieving real-time dynamic holograms. The researchers are confident that this will happen within the next few years (6). Through various trials it was found that a hologram created by applying 9 kV could be maintained for up to two hours without refreshing by applying just 4 kV (1). Still, these voltages are quite large compared to the 120 V used to power most American home appliances. Presently, images of near 90% diffraction efficiency can go through hundreds of write/erase cycles per month without the material showing any signs of degradation over several months (1). The holographic images described in this article were produced by reflection of a red reading laser. Future holograms will display full color as well as full parallax. (1)

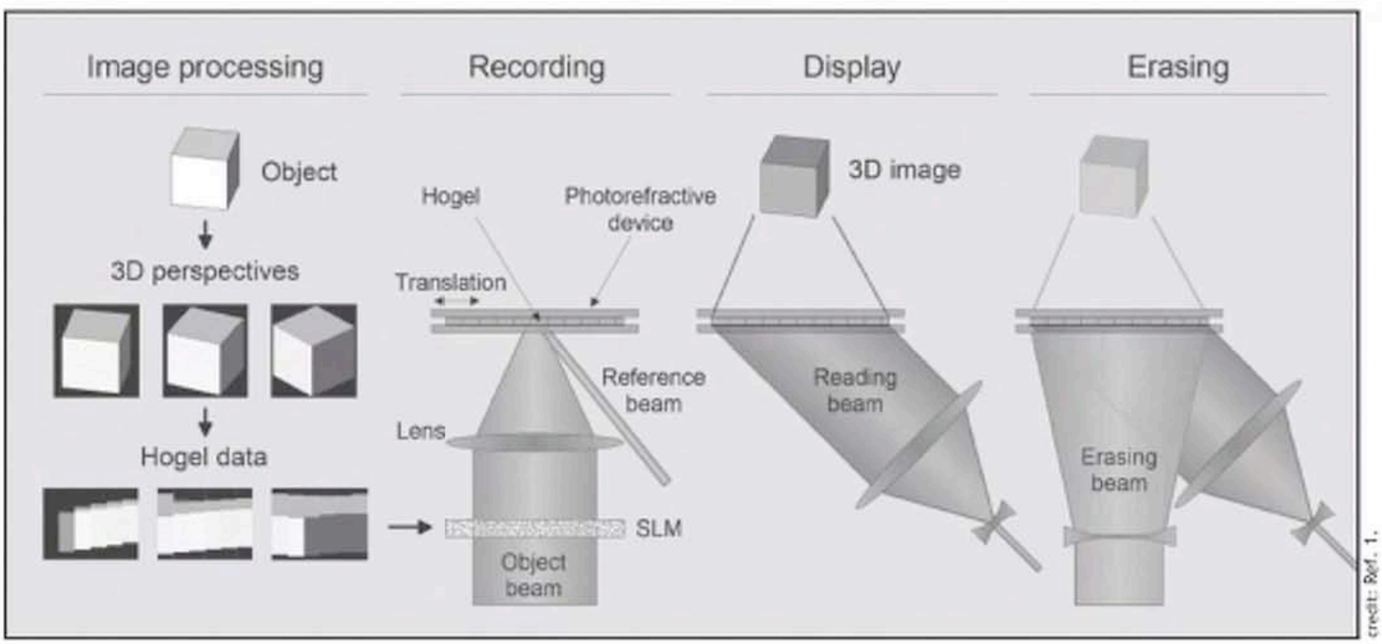
Possible uses of high-speed holograms

The 4 by 4 inch prototype, which is essentially a photopolymer film sandwiched between two pieces of glass coated with electrodes, is already stirring excitement in many fields. Pictures taken of any object from many 2-D perspectives can be assembled by the device into a 3-D hologram. So far images generated include a toy car, a molecular model, a human skull and a brain. The researchers anticipate the holograms infiltrating commercial markets in medicine, the military, entertainment, and other industries that require situational awareness (10).

At this point, progress in imaging technology has already enabled major advances in medicine. One example is the use of in vivo confocal microscopy to watch the accumulation of amyloid plaques in the brains of Alzheimer's patients (11). Other 3-D imaging techniques commonly used in medicine are MRIs (Magnetic Resonance Imaging) and CT (computerized tomography) scans. Despite the 3-D nature of the data collected by these imaging devices, it is still being displayed on 2-D computer screens and printouts (5). Real-time 3-D imagery would allow a surgeon to monitor the patient's condition during a lengthy or complex operation. It could also be useful for less invasive laparoscopic surgeries by circumventing the need for internal cameras. This new imaging system would facilitate collaboration as well, if a doctor in Boston could participate in a surgery being conducted in San Francisco courtesy of an updatable, life-size hologram of the patient (12). Finally, it could provide realistic models of molecular interactions for use during drug development.

Holograms have obvious applications to training and evaluation of models. One of the great benefits of holograms is that they do not produce side effects often associated with stereoscopic displays, such as eye fatigue or motion sickness (1). This would be of great relief to anyone enrolled in holographic driver's education or flight school. The Air Force currently uses static holograms in training but an automated process of capturing, writing and erasing holograms via a system that can take input from satellite or aerial photographs would add a new level of realism to the training (4). Fully realistic modeling for industrial, engineering, or architectural projects would also help alert designers to flaws in their work.

Aside from providing high-quality training and helping to preclude foreseeable hazards, this technology could also aid professionals working in dangerous situations. Airline and fighter pilots would become more aware of obstacles within their surrounding airspace. Emergency response teams



▲ ABOVE: A 3-D object is recorded in 2-D perspectives which are then reorganized (this process is what Hogel data refers to) and uploaded to a spatial light modulator (SLM) which controls the recording beam focused on the photorefractive material. The holographic object is displayed with the reading beam and the erasing beam allows the cycle to repeat.

could be kept abreast of rapidly-changing flood, fire, or traffic problems. Also, dynamic holograms of a battlefield could help a tactical control center better protect soldiers. For those of more pacifist leanings, ideally someday the battles themselves could be carried out by holograms!

Advertising and entertainment would also be areas very receptive to such an eye-grabbing innovation. Consumers already spend a great deal of money on holograms and it is likely that an updatable one would be well-received. Whoever made the first dynamic holographic billboard or full-length feature film would be sure to cause a sensation. In terms of marketing, if people went crazy for the iPhone, just imagine what they would do to get a hold of a "holophone"! The displays of video games could finally be on par with controls that have been designed to detect more life-like motions such as those of the Wii gaming system. That may mean more than just fun and games, since a study at Beth Israel Hospital has shown that surgeons who play video games at least three hours a week make nearly 40 percent fewer errors than surgeons who do not play video games (13). Since games completely unrelated to surgery such as Super Monkey Ball have this effect on dexterity and accuracy, it is likely that the impact of a surgical simulation could be even greater.

Finally, there is the role that dynamic holograms could play in information storage. It seems a natural fit, since the small prototype can already store a terabyte, the equivalent of 1000 gigabytes, of data (1). Colorado-based InPhase Technologies launched a holographic drive that can fit 300 gigabytes onto a standard disk and last for an estimated 50 years (14). However, the downside of photorefractive polymers is that they require expensive, high-power lasers. Furthermore, chief technology officer of InPhase Technologies Kevin Curtis believes that no technology that requires kilovolts of energy across thin media would be safe enough to use for storing critical data archives (6). Even for use in other media, this technology is currently hindered by its slow update speed. Competing 3-D technologies, though not true holograms, no longer require the viewer to wear special equipment and could limit the applications of this new display to those that do not require fast updates (2). Despite its critics, the Peyghambarian team continues to improve the technology by increasing imaging speed and decreasing cost. One idea they are working on is trying to write images faster by using pulse lasers (5). In any case, the vast potential market provides plenty of incentive to develop technologies that will add that extra dimension. H

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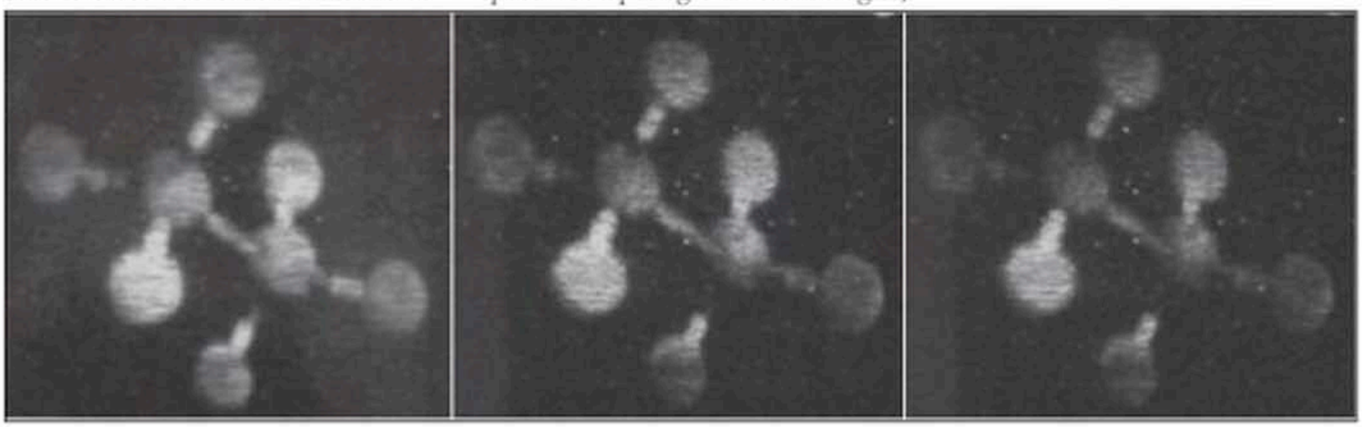
One of the great benefits of holograms is that they do not produce side effects often associated with stereoscopic displays, such as eye fatigue or motion sickness

▼ BELOW: Holographic molecular models could be used to test for adverse drug interactions before beginning animal trials.



credit: Adapted from Ref. 1.

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