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3D Data Storage

Norman Desmarais
Providence College, normd@providence.edu

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c/o Katina Strauch
209 Richardson Avenue
MSC 98, The Citadel
Charleston, SC 29409

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"Linking Publishers, Vendors and Librarians"

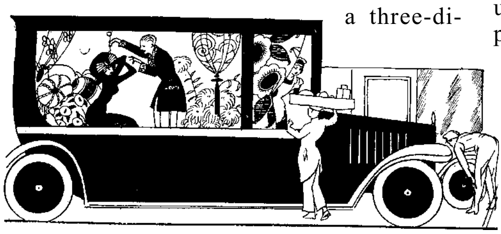
Innovations Affecting Us — 3-D Data Storage

by **Norman Desmarais** (Acquisitions Librarian, Phillips Memorial Library, Providence College) <normd@postoffice.providence.edu>

DVD superseded CD-ROM. Holographic data storage will eventually replace DVD. Demand for high-density data storage proceeds unabated; so engineers continue to search for ways to pack more data into increasingly smaller spaces. CD-ROMs packed 650MB of data onto a single layered disc. DVD found a way to put two layers on the same side of a disc. In addition to doubling capacity, it was the first three-dimensional storage medium. By putting two layers on each side, DVD can deliver up to 9GB of data. Holography promises to increase the number of information layers to ten and, eventually, to 100 or more. Holographic data storage differs from conventional storage techniques in that it uses the entire volume of the recording medium, rather than just the surface, thereby greatly increasing potential data density.

A hologram is created by splitting a laser beam in two. One portion of the beam illuminates an object with coherent light in which all the waves travel in phase with one another. The other portion of the same beam, called the reference beam, is directed at the photographic plate simultaneously, but it is reflected by a mirror or prism. Because the two beams take different paths, they are no longer in phase with each other when they reach the film and interfere. This interference pattern is recorded on the film and constitutes the hologram. To reconstruct (view) the image requires illuminating the hologram with a light shining from the same direction as the reference beam. The interference pattern (hologram) diffracts this light to reconstruct the light patterns from the original scene, rendering the original surface pattern of the object in three dimensions.

This works fine for images of objects; but digital data is not a three-dimensional object; so how can it can be recorded in holographic images? The data is usually represented as bright and dark spots, analogous to the ones and zeroes or charged and non-charged particles of conventional binary storage devices.



The Big Picture

A single hologram can store a very large amount of data because each "page" is recorded at a different angle relative to the plate. To read each page requires illuminating the hologram with a laser beam focused at the same wavelength, angle and polarization as the original reference beam. In other words, the address of the data is the angle and frequency of the reference beam. Rotating the beam slightly — as little as 1000th of a degree — allows recording a fresh "page" in the same hologram.

Holograms have a particular advantage in that they allow information retrieval with only partial information about the original content. The reading mechanism retrieves and transfers an entire "page" of data from the storage medium at a single time. A beam with only a partial image is sufficient to reconstruct a reference beam that can provide the address of the stored information content that corresponds most closely with the partial input information. This is significant for image-based data sets because they are difficult to process using relational database techniques. Holography permits searching a large volume of data simultaneously resulting in very fast data search rates. Rates of up to 100GB/s have been demonstrated under experimental conditions.

Developers have focused on two types of storage material. One approach uses a photorefractive ferro-electric crystal (lithium niobate). The other uses azobenzene polyesters in the form of an amorphous or liquid crystal. However, both the photopolymer and crystal methods have their problems. The material must be sensitive enough for a low-powered laser to read and write on it but not so sensitive that the laser does not obliterate data in the retrieval process. The photopolymers enjoy high photosensitivity, high dynamic range, and ease of processing for display; but they have a shorter "shelf life" than crystals. The crystals, on the other hand, must be "fixed" so that the reading laser does not destroy the information during the reading process. Holographic storage media have a projected life expectancy of up to a hundred years because they are more resistant to temperature fluctuations, water, acid, and electrical fields than traditional storage media.

Fluorescent Multilayer Discs

One effort at holographic data storage uses fluorescent multilayer discs (FMD) developed by **Constellation 3D Inc. (C3D)** in New York. FMD technology uses fluorescent dye instead of the reflective and semi-reflective coatings used by CD-ROMs and DVDs. They can support up to ten information layers on each side of a disc and match the density and transfer speeds of DVD.

The fluorescent dye allows the laser beam to travel deeper into the medium with less noise (stray light) and interference in the return signal because when the focused laser strikes a pit on one of the information layers, the fluorescent light that's reflected has a higher wavelength than the laser. In other optical media, more layers produce more stray light, making it difficult to distinguish the signal from the noise, particularly if the noise is the same wavelength as the signal. With fluorescent multilayer discs, the fluorescent light carries the information; and the read device filters out the stray light and only reads the signal. This configuration permits the use of more information layers because it's better able to distinguish the signal from the noise.

While the cost of a single FMD will probably be higher than that of other storage media, the cost per gigabyte should be considerably lower if the FMDs now in development can hold the projected 140GB of data. In contrast, the next-generation of DVDs are expected to contain 20GB.

InPhase has a prototype hologram disc the size of a CD that can hold up to 400GB of data and retrieve it at the rate of about 30MB per second.

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That's roughly equivalent to downloading a DVD movie in about thirty seconds. **IBM** is developing a system that stores 250GB in a hologram no larger than a square inch. Another approach proposes to use a photosensitive crystal the size and shape of a sugar cube to store 1 terabyte of data.

The **Photorefractive Information Storage Materials** consortium **(PRISM)** and the **Holographic Data Storage System** consortium **(HDSS)**, under the aegis of the **Defense Advanced Research Projects Agency (DARPA)** have been experimenting with the development of new and improved holographic media, spatial light modulators, and detector arrays, as well as the opto-mechanical components needed for high performance system implementations.

Blue Light Specials

All of the technologies discussed so far use red lasers. Scientists have also been working to develop devices that use blue lasers that have shorter wavelengths and, consequently, greater storage capabilities. The blue lasers would burn smaller pits to cram more data onto the storage medium. That would be comparable to shrinking car sizes and parking them closer together to increase the capacity of a parking lot. However, blue-laser devices haven't made it out of the laboratory because they remain too unwieldy for commercial applications. The main problem is that the heat they generate makes blue lasers very difficult to function reliably at room temperature; but **Jan Oosterveld**, a member of **Philips Electronics** NV's group management committee says: "We are not so far away from producing blue-laser DVDs in mass quantities."

Sony, **Matsushita Electric Industrial**, **Hitachi**, **Pioneer**, **Sharp**, **Samsung Electronics**, **LG Electronics**, and **Thomson Multimedia** have recently agreed on uniform standards for next-generation blue-laser DVDs which may appear as early as next year. These new discs promise capacities of up to 27GB on one side of a single 12cm disc — enough to store more than two hours of digital high-definition motion video. That's nearly six times the 4.7GB capacity of current DVDs.

The key factors that will determine the success of a holographic data storage system are: useful capacity, transfer rate, and access time. A holographic data storage system also has to be cost-competitive at the same time it delivers improved performance over other conventional optical and magnetic drives.

Crystal Ball

Holographic data storage has a bright future as smaller and more powerful lasers get developed. It can expect competition from other optical storage technologies, particularly DVD, which may employ some kind of volumetric storage scheme. This could entail the use of multilayer discs or even a holographic approach to increase data-storage capacity. Data transfer rates of multilayer technologies are much lower than those of holographic systems; so DVD may rely on blue-laser technology, holography, or a combination of both.

Holographic data storage will require a new and costly manufacturing infrastructure to meet market demands for competitively priced products in sufficient quantity and quality. Polymer-based systems may be the first on the market because they leverage the existing manufacturing infrastructure better than the crystal-based, all-solid-state devices. They also allow write speeds 100 to 1,000 times faster than those using crystals.

Holographic devices may eventually appear in all kinds of small portable appliances and electronic devices, such as mobile phones, handheld computers, video recorders, PCs, digital cameras, and high-definition TVs. They also offer great portability as they permit storing gigabytes of data on a disc the size and shape of a credit card.

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