Electro-holographic display enhances car engineering

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Interferometric holography using interfering beams of light has been under development for some 50 years, but computer-generated holography is a more recent development. Instead of using the light from an object to form an interference pattern, the intensity pattern is computed from data held in computer memory. The 'object' from which this pattern is formed might exist only as a numerical description. Signals from the computer can be fed to a re-configurable device able to modulate light, such as a spatial light modulator or a microdisplay (see Fig. 1), which can diffract coherent light to form a real three-dimensional (3-D) image from the data stored in the computer. Therefore, developers do not have to spend time making a solid model of the object under study when such 'virtual prototyping' is used.

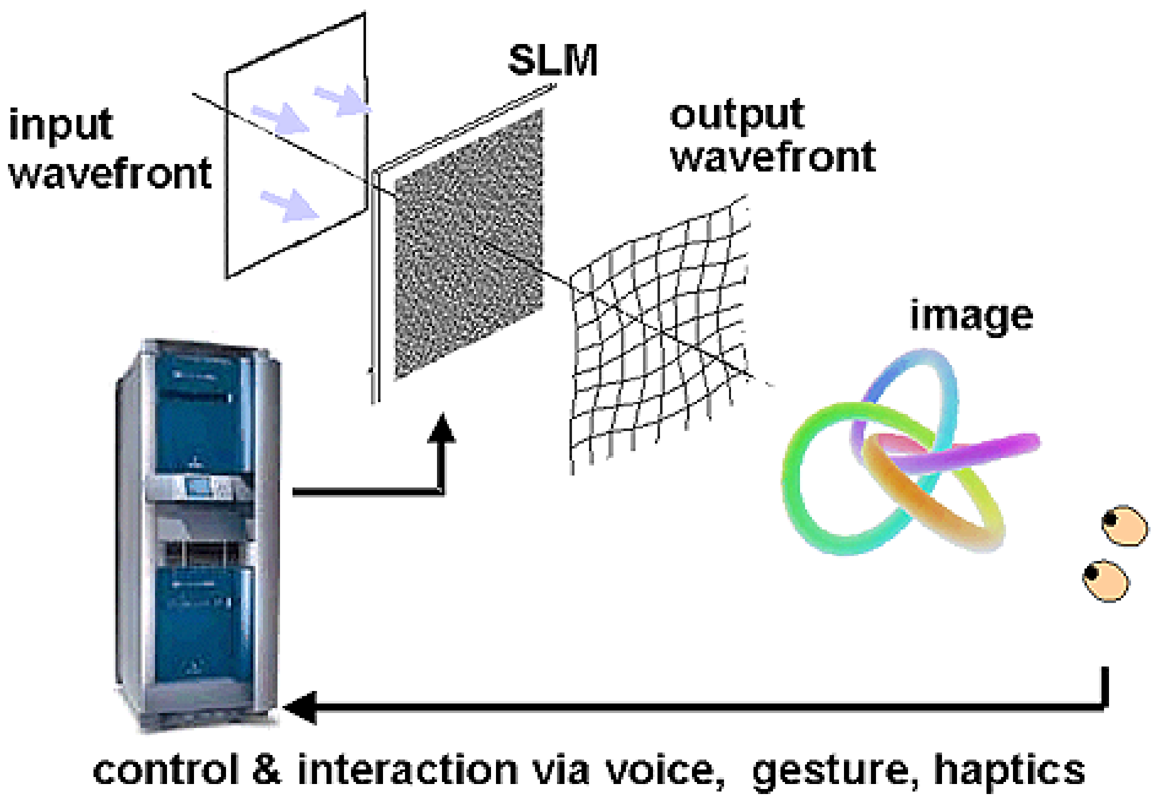

FIGURE 1. In an interactive computer-generated holographic system, the computer calculates the holographic fringe pattern displayed on a spatial light modulator (SLM). Laser light illuminates the SLM to produce a light wave that diffracts to form a three-dimensional image. The viewer can then interact with the image. The computer recalculates the holographic pattern to allow the re-display of the modified image.

However, a complex problem in designing such systems for practical applications involves the need to rapidly process extremely large amounts of data because high-resolution interactive holograms can contain some 10 billion pixels. Until now, this problem, together with the design of complex spatial light modulators able to handle such high pixel counts, has prevented the introduction of practically useful computer-generated interactive holography systems.

Recently, Qinetiq (formerly the Defence Evaluation and Research Agency; DERA; Malvern, UK; www.qinetiq.com) has found ways to calculate and display holograms of more than 5 billion pixels. Its approach has generated images of reasonable size and resolution from computer data. This has not been possible previously with such large numbers of pixels owing to computational limitations that significantly affect costs. These costs are closely related to the type of computer-generated hologram selected, the algorithm used to compute the hologram, and the computer architecture used for implementation of the system.

To reduce hologram system costs, a joint venture company, Holographic Imaging LLC (Royal Oak, MI, USA; www.holographicimaging.com), has been formed by Qinetiq and the Ford Motor Co. (Dearborn, MI, USA; www.ford.com) to apply computer-generated holography to industrial applications. Holographic imaging is initially using an interactive imaging technology developed at Qinetiq to assist in the design of new automobiles. Qinetiq has spent five years working with Ford on computer-generated holography for automotive design. The on-going development work is continuing at Qinetiq.

Ford Motor says this technology is expected to save several millions of dollars in the design and development of new vehicles. The technology is also projected to provide customer feedback on new vehicle designs more quickly than currently possible. It is forecast to reduce automotive development time from a several years to about 14 months.

The UK Ministry of Defence will retain the use of the technology to achieve similar advantages for important military applications, including training, where the system may be able to provide highly realistic three-dimensional images. In fact, the ministry claims that the approach currently being developed will provide the highest perceived three-dimensional image quality of 'replacement reality' yet possible. The technology will also permit a broader range of designs to be considered.

The choice of algorithm to form a computer-generated hologram is affected by the desired image characteristics, the required computation times, the image artifacts that are acceptable, and the particular applications of the system. Qinetiq has worked on two types of algorithms chosen for their practical use in a future interactive workstation. They are interference-based and diffraction-specific algorithms.

The interference-based algorithm closely simulates the propagation of light in a conventional interferometric hologram recording. It is able to generate high-quality images by incorporating lighting effect and surface reflection properties. Depth cues also can be reproduced with which human visual systems are familiar.

The Qinetiq Coherent Ray Trace algorithm is based on this approach using Fourier transform geometry and an off-axis object. The calculation requires around 100 TFLOPS (100 million-million floating operations per second). This large computational load has motivated Qinetiq to develop another set of diffraction specific algorithms that offer a trade-off between image quality and operational speed. These algorithms allow the computations to provide a resolution matching that of human vision, rather than the over-resolution that is commonly found with interference-based images.

In addition to the required high pixel count, the modulator for an electro-holographic display must meet the need for rectangular formatted holograms of some 10 billion pixels with an interpixel spacing of 5 microns. Because these images must be updated at video rates, the bandwidth of the electro-optic modulator system should be over 10-billion bits per second. It also is important that early monochromatic display systems be upgradeable to color and higher pixel counts.

During a research study, Qinetiq found that there are no commercial modulator solutions currently available that are close to meeting the demanding requirements of holographic display systems. And, few technologies offer the long-term potential to achieve the required level of performance. However, Qinetiq researchers have combined a unique combination of modulator technologies to significantly raise the performance of electro-optic modulator systems and therefore meet all the system holographic requirements.

This approach exploits the high frame rate of medium complexity, electrically addressed spatial light modulators (EASLMs) and the high resolution of optically addressed spatial light modulators (OASLMs). It results in a system that can display images or patterns with significantly higher pixel counts than previously possible. In this system design, some of the temporal bandwidth of the EASLM is traded off for the spatial bandwidth of the OASLM. This design enables higher pixel counts to be written while maintaining the overall video update rates.

Called Active Tiling, this modulator system is composed of an EASLM to act as an 'image engine' that can display the computer-generated hologram image elements quickly; replication optics to project multiple de-magnified images of the EASLM onto an OASLM; OASLMs to store and display the computer-generated pattern; readout optics to form the holographic image; and a control system to synchronize the complete system. This modulator system is designed to allow multiple channels to be assembled to produce a continuous output modulation plane. And, system performance can be adapted or extended to meet different application requirements. OASLMs use optical intensity patterns to modulate light, whereas EASLMs use electrical signals from electrical conductors.

The spatial light modulator system (see Fig. 2) operates by breaking up large computer-generated hologram data sets into segments that are displayed sequentially on an EASLM. These segments are projected onto the photosensor of a liquid crystal OASLM through replication optics to form multiple images of the EASLM at the OASLM photosensor. An image segment can be stored on one region of the OASLM by switching the liquid crystal at that region. A new data segment is then loaded onto the EASLM and transferred to an adjacent region on the OASLM until a complete image has been written. The complex, high-resolution computer-generated pattern thus written onto the OASLM can be read by coherent illumination to replay the hologram.

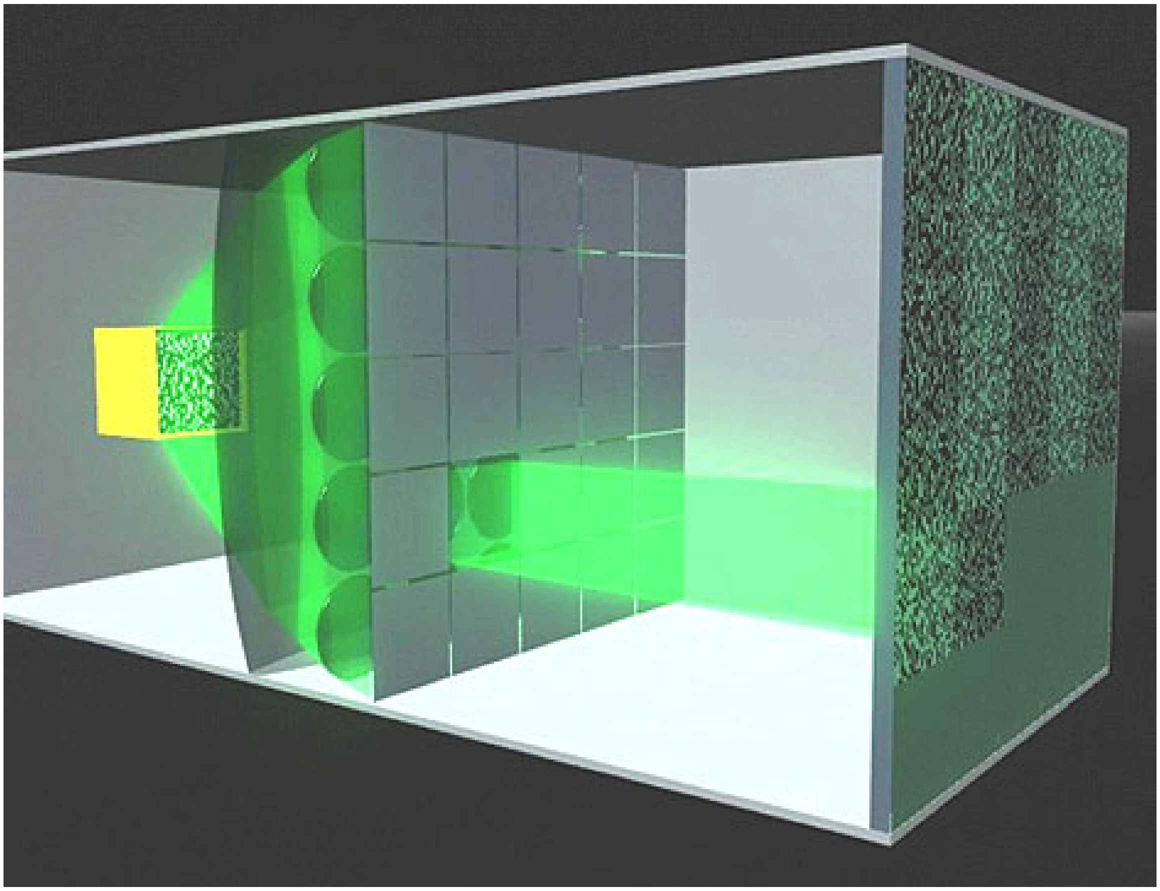

Figure 2. Active Tiling modular system uses an electrically addressed SLM as an 'image engine' that can display the computer-generated hologram image elements quickly. Replication optics project multiple demagnified images of the EASLM onto an optically addressed SLM, which stores and displays the computer-generated pattern. Readout optics form the holographic image. This modulator system allows multiple channels to be assembled to produce a continuous output modulation plane.

For example, images from a 1k x 1k pixelated EASLM are projected through a 5 x 5 replication system (see Fig. 3) to form a 25-Mpixel (5k x 5k) image. The complete image can be updated at 1/25 of the rate of the original EASLM. The latter may operate at a frame rate of more than 1 kHz, giving an image update rate of over 40 Hz. A number of Active Tiling channels can be operated in parallel, each receiving data from its own host computer interface.

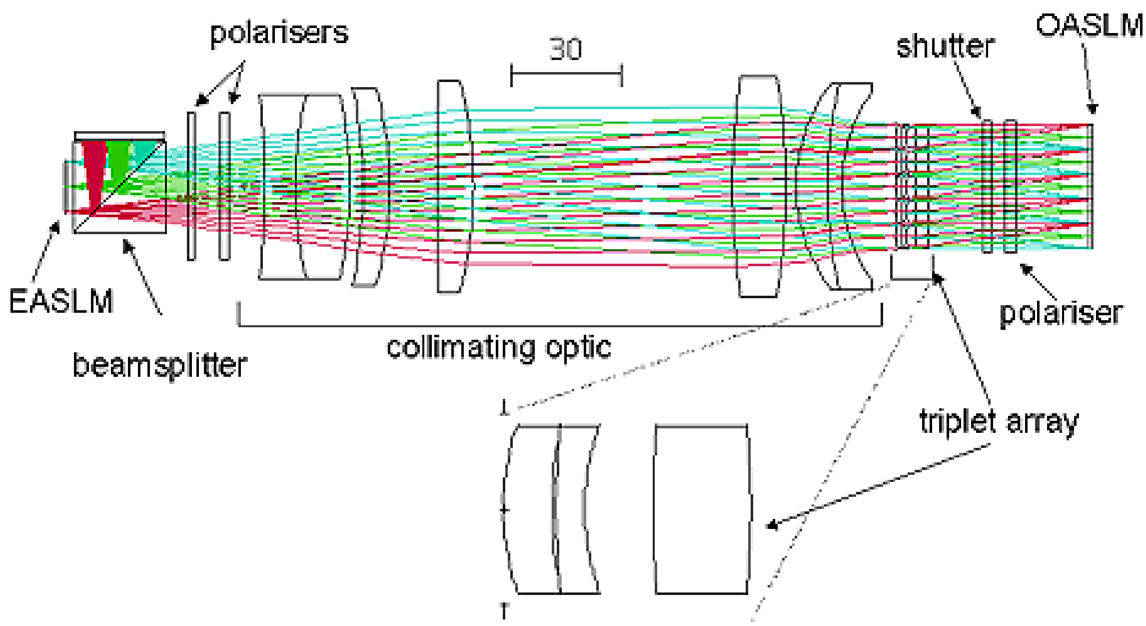

Figure 3. Images from a 1k x 1k-pixelated electrically addressed SLM are projected through a 5 x 5 replication system to form a 25-Mpixel (5k x 5k) image. The complete image can be updated at 1/25 of the rate of the original EASLM. The EASLM can operate at a frame rate of more than 1 kHz, giving an image update rate of greater than 40 Hz. A number of Active Tiling channels can be operated in parallel, each receiving data from its own host computer interface.

Although the Active Tiling system spatial bandwidth product may be higher than 80 Gbits/s, each parallel data path can operate with the bandwidths of current high-performance graphic monitors. This technique enables gigapixel holographic images to be updated at video rates.

Ferroelectric-liquid-crystal elements on CMOS silicon-based EASLMs provide attractive features for replaying holograms within Active Tiling. They can operate at high frame rates since their fast device addressing circuits are in the silicon backplane. Pixel sizes can be in the 10 to 20-µm range. The optical system is now being improved so that it can replay 5k x 5k pixels with a 6.5-µm pitch at an OASLM photosensor.

The data pattern must be projected with a uniform light intensity across the OASLM to achieve even switching as data are delivered to its various regions. Therefore, the spatial intensity across the EASLM and the angular distribution of the light must be uniform to ensure that each replication lens aperture receives equal optical power. This is currently achieved by expanding the 514-nm light from a 2-W argon ion laser spatially and passing it through a diffuser located as close as possible to the EASLM. Charge spreading in the photosensor layer and the minimum stable ferroelectric crystal domain size set the fundamental limit to the OASLM resolution. Further work is being undertaken to isolate these issues. Ferroelectric liquid crystals allow the image to be stored on the OASLM so that it can be repeatedly read without reloading the data, if necessary.

At the current state of development, a single-channel Active Tiling system has been demonstrated that replays holographic images from 6-Mpixel data patterns written on an OASLM. Industry standard CAD data files are used as the data source. A diode laser emitting at 670 nm is used for replaying the images. Appropriate interfaces are also being developed to allow viewers to interact with and manipulate the three-dimensional images generated by the system. For most applications, it is envisaged that intuitive techniques, such as voice, gesture, and haptics will be used.

The Qinetiq group suggests that practical useful systems may be possible within three to five years. The sophistication and cost of the displays will initially limit their use to such fields as design in the automotive and aerospace industry and data visualisation in the petroleum and biochemical industries. Other three-dimensional display techniques have not yet produced the desired image attributes in these applications. Other applications may benefit later as the technique matures.