Volumetric 3-D Liquid-Crystal Displays

Until recently, true 3-D displays have not proven to be practical except for a very narrow range of applications. Could LCDs bring volumetric displays to a wider audience?

by Igor N. Kompanets and Sergey A. Gonchukov

MOST of the displays we call three-dimensional (3-D) merely create the illusion of a 3-D world on a 2-D screen. This illusion is a far cry from the rich 3-D world that could be created with a high-quality volumetric display that fully recreates a scene within a volume of 3-D space.

A good 2-D display can exhibit in the neighborhood of 1000×1000 (10^6) pixels. An equivalent 3-D display must also exhibit 1000 pixels of depth, or $1000 \times 1000 \times 1000$ (10^9) voxels (volume pixels). Unfortunately, it is not feasible to implement such a display. So, we are faced with a basic question: Is it possible to build a true volumetric display that offers sufficient quality at a less-than-ridiculous cost?

Volumetric displays are under development and investigation all over the world. The range of applications is extremely wide and includes volumetric TV, the display of dynamic scenes and complicated technological and geophysical processes in video-information systems, computer simulation and design, navigation, visualization of tomographic information in medicine, simulation of different tasks in science and technology, computer trainers and games, advertising, and entertainment.

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2-D and 3-D

Developers are now making good progress in fabricating 3-D displays that use 2-D screens to form different points of view. But, as previously indicated, this type of 3-D display can not form the volumetric image needed for the 3-D model of an object, which requires a real 3-D image that can be observed from different sides by many observers simultaneously, thus enabling them to look around the object. Such an image can be formed only in a 3-D medium, slice by slice along the z-axis (the direction of depth into the display).

This approach makes a relatively modest demand on computer resources because points of view are not specially calculated, but are observed naturally by any observer when looking around the volumetric image. Of course, this entire image must be formed in 1/25 sec or faster if it is to be perceived without flicker.

For a long time, there was no appropriate volumetric medium with which to design an effective 3-D display. It was only about 2 years ago that the Perspecta™ 3-D System,

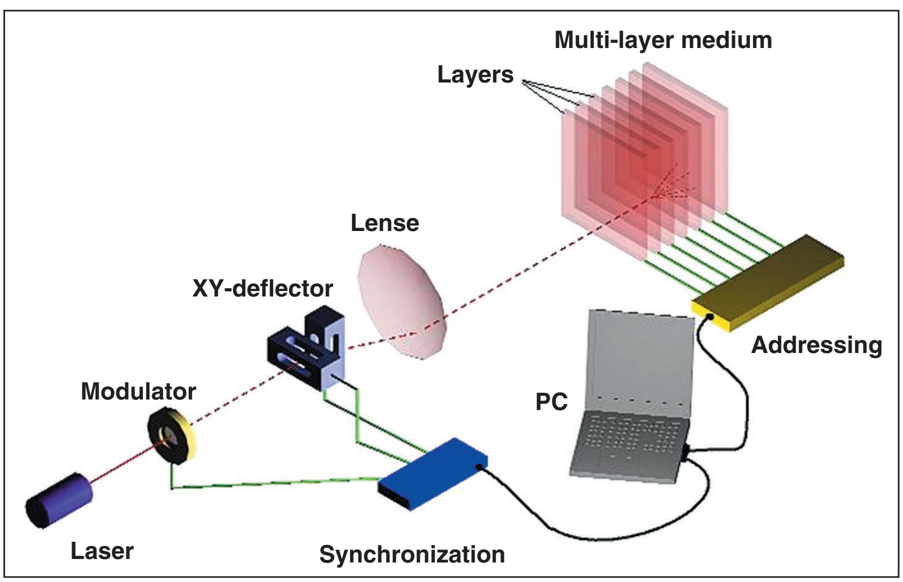

__Fig. 1:__ This volumetric 3-D display system employs a multilayer FLC medium and optoelectronic addressing.

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made by Actuality Systems, Inc. (Burlington, Massachusetts), was first demonstrated. The system uses an optomechanical method for voxel addressing. A 2-D fluorescent or light-scattering plate – which serves as the screen – is fastened to a rotated disc that imparts to the screen periodical translations along the z-axis – the axis of image depth. The screen is illuminated with an xy-scanned laser beam. Software and the plate profile compensate for the different linear velocities of different points on the plate.

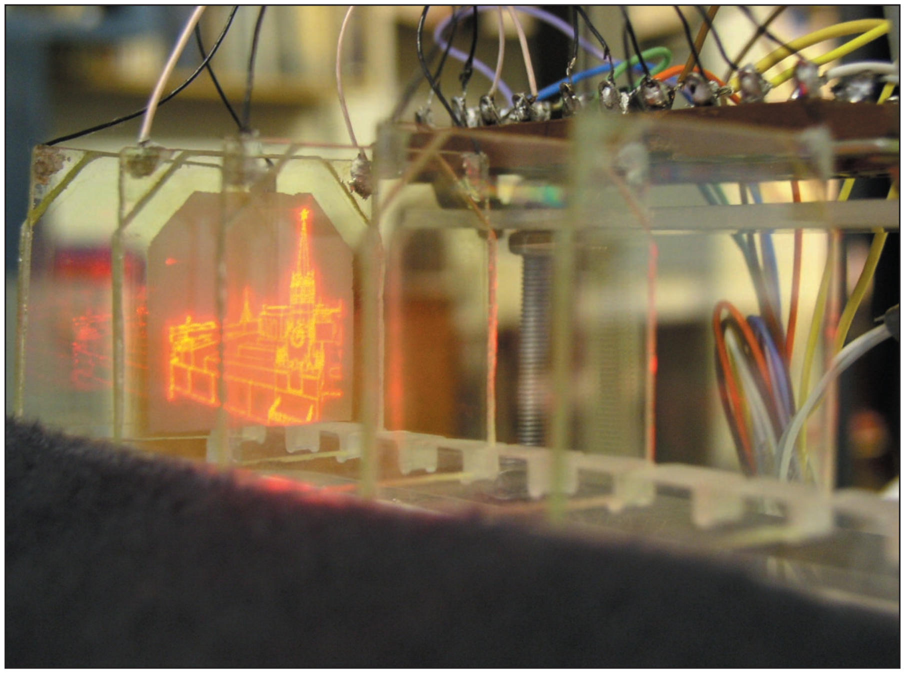
The Perspecta™ optomechanical system represents a substantial step forward in volumetric displays, but there are disadvantages. The system has rapidly moving components that require a protective cover and a relatively small part of the space under the cover is devoted to the effective display volume.

Using Liquid Crystals

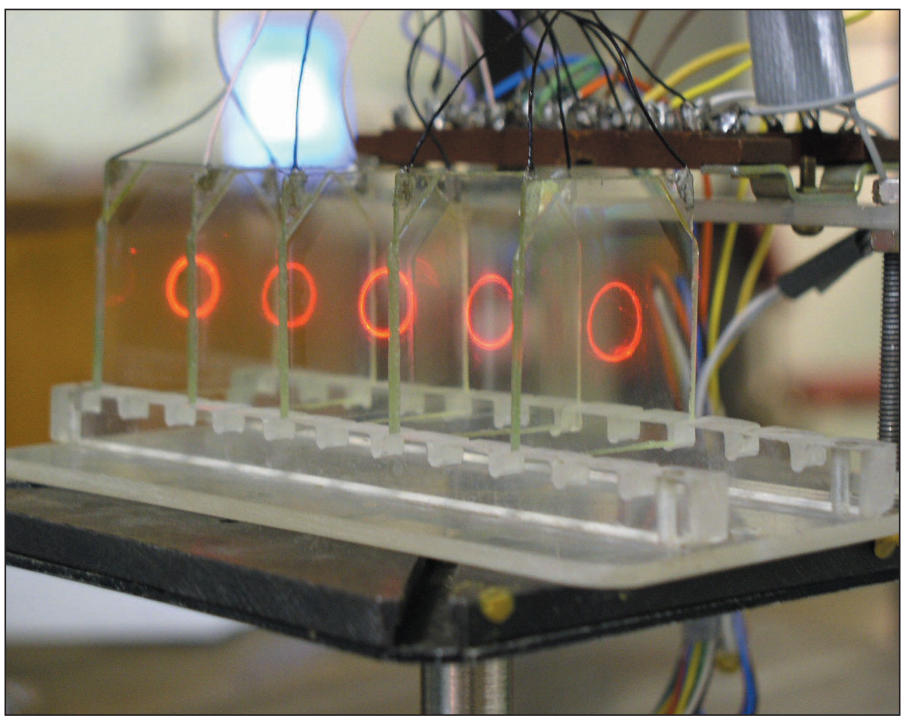
Could liquid-crystal layers be used as a non-moving volumetric medium for a 3-D display? For many years, a research team at the P. N. Lebedev Physical Institute has studied electro-optics and the application of both nematic and smectic ferroelectric liquid crystals. Some of these materials – the fastest of which has an on/off switching time of a few microseconds – were used in spectacle-type modulators that utilize a light-polarization change that allows viewers to see stereo images on a computer monitor. Cells with polymer-dispersed ferroelectric LC (PDFLC) were studied to determine their suitability for flexible displays, and 15–100-sec response times were achieved in such cells. An intensive light-scattering mode was observed in these materials when the refractive indices of the polymer and the FLC were matched and then changed under electrical voltage.

On the other hand, a research team at the Moscow State Engineering Physics Institute manufactured and studied an excellent 2-D acousto-optic light deflector based on two TeO_2 crystals. Software has been developed that expands dynamic 2-D images produced by this deflector onto a large screen.

These two technological threads were woven together in a proposal aimed at creating a 3-D display based on an FLC or PDFLC volumetric medium (Russia Patent No. 2219588, granted on December 20, 2003). The principle of such a 3-D display is very simple (Fig. 1). Light scattering is used to visualize the z-axis (depth) "slices" of the 3-D scene.



(a)



(b)

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Fig. 2: *(a) A fragment of an image of the Kremlin has been written by a scanned laser beam and visualized by light scattering from a single LC layer. The other cells are transparent, and the picture is observed through them. (b) Rings are formed on all five LC layers sequentially.*

As in the optomechanical 3-D display, a laser beam scans a 2-D plane, and a 2-D image which is adequate to define a slice of the 3-D image is formed. The 2-D image slice is formed by the light scattered from the selected layer of the multilayer electro-optical medium when voltage is supplied to that layer. After the 2-D image slice is formed, the voltage on the selected layer is switched off, light scattering is stopped, and the layer becomes transparent. But the persistence of the human visual system keeps the slice "visible" for about 100 msec. Then the light scattering is provided to another layer, then a third one, and so on, until all the desired slices are formed and an entire 3-D image is visualized for the vision-persistence period. The process is similar to displaying the information on a 2-D display with one difference. In a 2-D display, the row information is stored and presented row by row; here, the slice information is stored and presented slice by slice.

Such a system does not have moving mechanical parts, and the entire volume can be observed, nearly from all sides. The layer size is scalable, and the layers themselves could be demountable. Of course, three laser beams – one for each primary color – would have to be used in a full-color 3-D display.

The basic requirements for a 3-D display system of this optoelectronic (light–voltage) type are fast on/off switching, wide-angle and high-contrast light scattering, and the elimination of light losses. Our experience indicates that FLC- and PDFLC-based multilayer media could satisfy the first requirement. Liquid-crystal compositions, layer orientation, large-sized technology, scattering parameters, and voltage regimes can all be optimized.

The main problems are to reduce the light absorption and depolarization in the layers and to match the refraction index in order to suppress reflections on layer boundaries (anti-reflection or liquid layers can be used for this). Estimations indicate that these problems can also be solved in the foreseeable future, with the result that it should be possible to provide a medium with more than 100 layers for a real-time 3-D display.

Testing the Volumetric LCD

To test the concept of a volumetric LCD, we created a simple experimental model of a 3-D display controlled by a personal computer. The optical part of the display consisted of a helium–neon laser with 1.5-mW beam power, 6-mm aperture, and diffraction divergence; a 2-D acousto-optic deflector that does not take more than 10 sec to address any of 500 × 500 points at an angle of 0.05 rad; and some optically matched elements to form 2-D images for the voltage-selected slices. Five LC cells with a 4 × 4-cm aperture that were shifted 2 cm from each other composed the volumetric multilayer medium. The thickness of the LC layers was 10 μm, and the light-scattering switching on/off time was about 1 msec. The LC cells were not optimized, and liquid or anti-reflective layers were not used at this stage.

Software permitted the formation of different static and dynamic images on any LC layer, scattering light at a particular moment. A photo-camera was able to photograph a 2-D slice pattern with a short exposure time [Fig. 2(a)]. The other cells were transparent, and the image of the Kremlin can be observed through them.

In this model, layers were usually switched on and off in turn, and rather long exposure times close to the vision-persistence time permitted the visualization of all slice patterns together – similar to an entire 3-D image [Fig. 2(b)]. These slice patterns on a limited number of LC cells are not very dramatic – the slices, all ring patterns, are identical. But one can imagine a pipe which the viewer can look around and into.

Where We Are

Both of the photographs in Fig. 2 are evidence of wide-angle intensive scattering. The phenomenon's physical mechanism, as well as the technological issues already mentioned, are being investigated now. But we already believe that liquid-crystal layers can be used successfully as the volumetric medium for a real-time optoelectronic 3-D display. ■