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Micropolarizer-based multiple-viewer autostereoscopic display

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ABSTRACT

Autostereoscopic displays effectively "steer" different image-bearing bundles of light rays to the two eyes of the observer(s). Typically, each observer has to find an imaginary point or line in space upon which to place her nose, or an active system tracks a single observer, aiming the imaginary point or line toward her nose via some sort of face tracking scheme. This paper describes a system of the second type that is specifically adapted to accommodate several arbitrarily-located viewers while maintaining good optical isolation of a stereoscopic pair of images, and while registering them so that the consonance of accommodation and convergence occurs at the front surface of the display for maximum comfort during interaction.

Keywords: Autostereoscopic, micropolarizer, specular, display

1. BACKGROUND

Many autostereoscopic displays have been based on micro-optical technology, typically lenticular sheets comprising vertical cylindrical lenslets no wider than the intended pixel size.[1] A second category of systems is based on macro-optical elements, typically large lenses and mirrors that direct light from sources to the separate eyes of the viewer. Weiss has dubbed such systems "specular displays".[2] In an early example of such a system, one of a stereo pair is projected onto a large positive lens (serving as a "projection screen" or "field lens" as it were – we call this a "lens screen"), and the intended eye is placed in the real image of the projection lens formed by the lens-screen (an equivalent function can be served by a large concave mirror). A second projector near the first sends an image to the expected location of the second eye, so that a viewer in the correct location can fuse a stereo pair to gain an impression of depth in the image.[3]

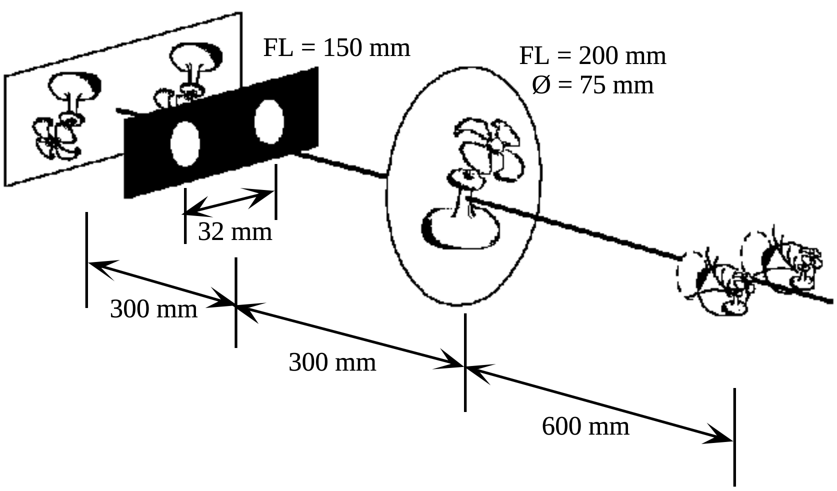

Figure 1. Diagram of Maxwell's autostereoscope.

This theme has been pursued by many inventors in the field of autostereoscopic displays, especially in the former USSR.[4] An interesting twist on the general approach occurred when Mahler introduced non-scattering transparencies in front of a

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large lens, with only a simple light source at what had been the projector lens location. Two such images were combined with a beamsplitter to form the "Photoplastikon," an autostereoscope that was manufactured briefly by Reichardt in Austria.[5,6]

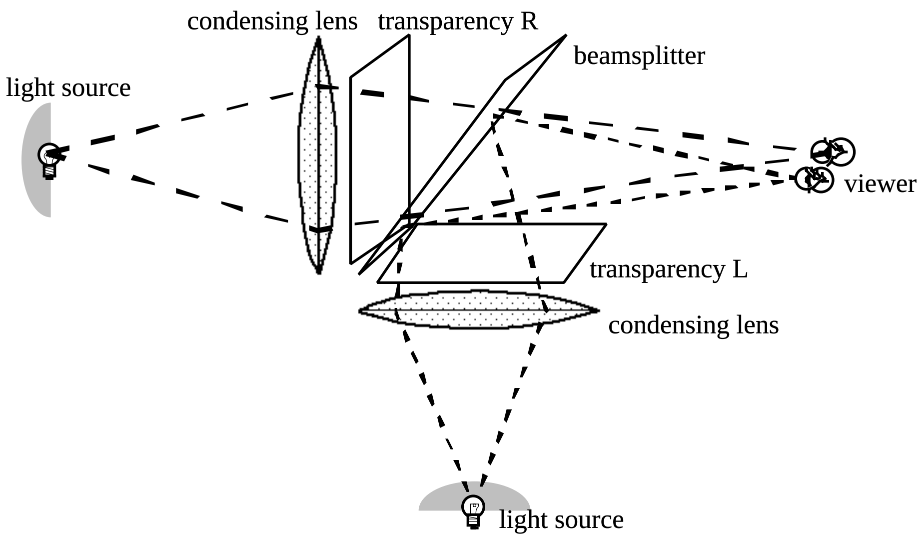

Figure 2. Adapted from Mahler's "Photoplastikon."

Because modern liquid-crystal display screens (LCDs) do not scatter light (except for diffraction), they can replace the photographic transparencies in Mahler's design, as several groups have shown.[7,8] However, because the "central plane" of the images (the surface where accommodation and convergence can be consonant, such as at the surface of the LCDs) is physically separated from the front of the display housing by the beamsplitter, immediacy and interaction are diminished. Christie approached this problem with a projection method,[9] while the present system uses a spatial-multiplexing method.

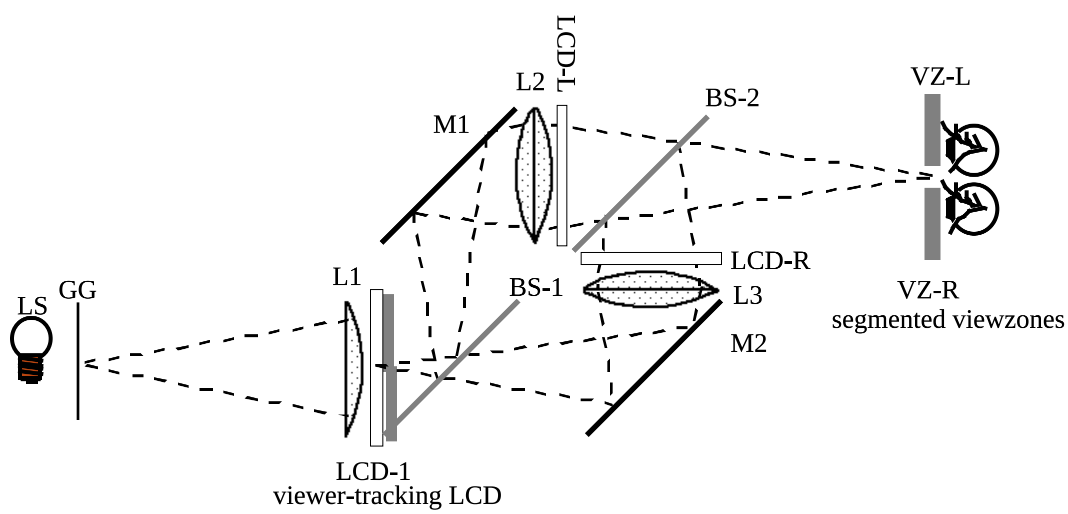

Figure 3. One of Christie's autostereoscopic displays.

2. FRONT-SURFACE DISPLAYS

One way to overcome the distancing of the central plane is to place an LCD at the front surface of the display and to "share" it among the two (or more) images by, for example, temporal or spatial multiplexing. Alternate-row spatial multiplexing is the method we have adopted for this system. That is, the even-numbered rows of the right-eye image are sent to the even-numbered rows of the display LCD, and the odd-numbered rows of the left-eye image are sent to the odd-numbered rows of the display LCD. Various methods can be used separate the light from the sets of rows to the two eyes. For example, Trayner and Orr use interdigitated holographic optical elements with good effect.[10,11]

Our system uses interdigitated strips of polarizer of orthogonal polarization selection, which are located upstream of the LCD panel. This is the type of sheet that Faris has referred to as a “micropolarizer array,” [12,13] one that has been fabricated to have narrow horizontal strips of linear polarizer oriented at plus or minus 45 degrees. The same result can be produced by a “microretarder array” that consists of narrow horizontal strips of birefringent material selected to have a retardance of one-half wavelength, so that it can rotate the plane of polarization of a beam, alternating with strips of non-birefringent material, followed by a single linear polarizer. If the “fast” or “slow” axis of the birefringent material is vertical, then a beam linearly polarized at +θ° will emerge polarized at –θ°. Thus a beam polarized at +45° will emerge at –45°, a rotation of 90° producing orthogonality of the polarizations. If the microretarder array is followed by a linear polarizer oriented at +45°, then the sandwich is the functional equivalent of a micropolarizer array for our purposes, with the advantage that the exiting light is of uniform polarization orientation.

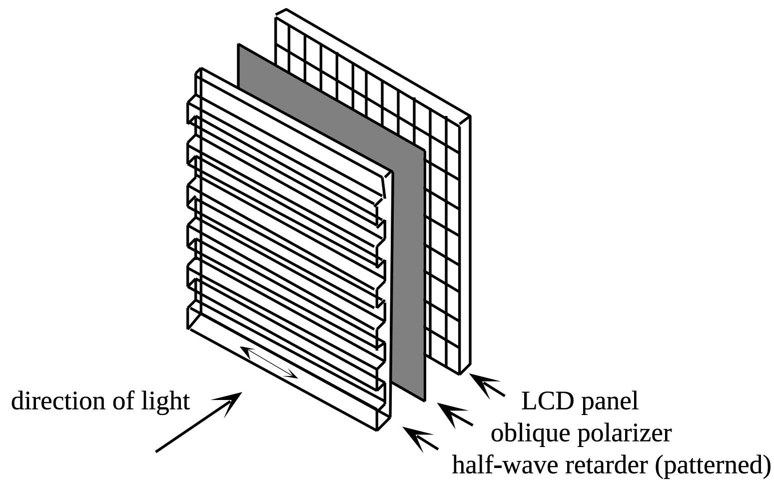

Figure 4. Microretarder array & polarizer sandwich.

Now, if a Maxwell-like autostereoscope is constructed by replacing one of the projectors with a +45° polarizer over a light source, and the other projector with a –45° polarizer over a second light source, and by placing the micropolarizer array and LCD display just downstream of the large lens, we have a display in which the even-row image is visible only from the intended right-eye position, and the odd-row image is visible only from the intended left-eye position. Note that in this case the micropolarizer array is on the upstream side of the LCD compared to the usual downstream location for use with polarized glasses.

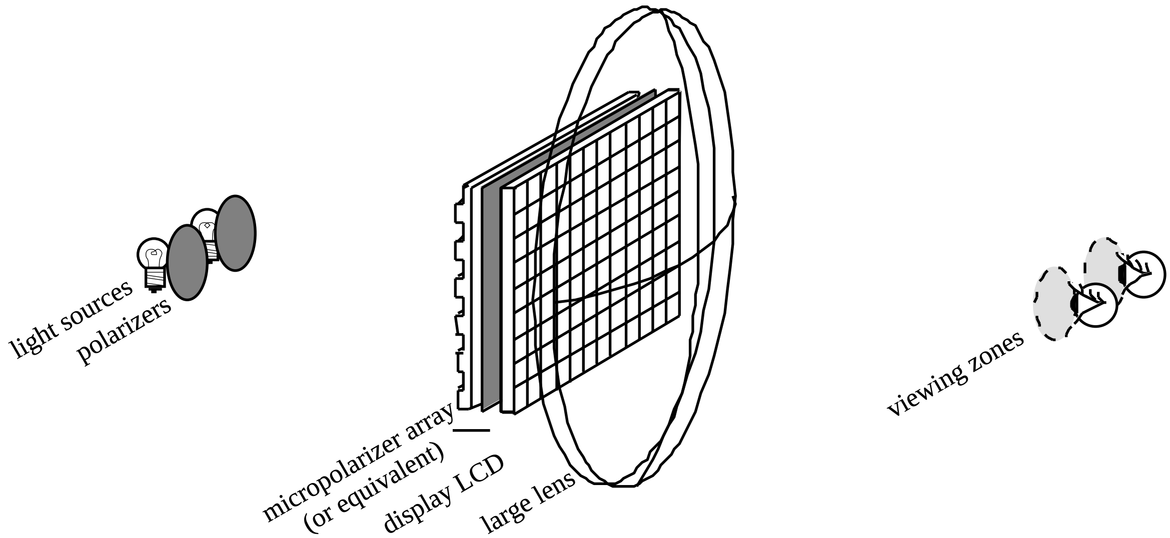

Figure 5. Schematic diagram of an autostereoscopic display.

In our system the two light sources and two polarizers are replaced by a single twisted-nematic (TN) type LCD panel with the downstream "analyzer" polarizing sheet removed, acting as a voltage-operable polarization switch (we will call this the "viewer-tracking LCD" for reason that will soon become clear). The usual operation of a TN LCD panel is to rotate the linear polarization of the incoming beam through 90° where there is no electrical field present, and transmit the incoming beam unmodified where the maximum voltage is present. Because the input and output polarizers are normally perpendicular (aligned with the orientation or "rub" directions of the liquid crystal element surfaces), the panel is "open" or "clear" in the "voltage off" condition, and "closed" or "dark" in the "voltage on" condition. Without the output polarizer, the panel acts instead as a polarization "90° rotate" or "no rotate" switching device with good accuracy. An advantage of using this approach is that the zone producing, for example, +45° polarized light intended for the viewer's right eye can be moved quickly from place to place by changing the video drive to the LCD panel.

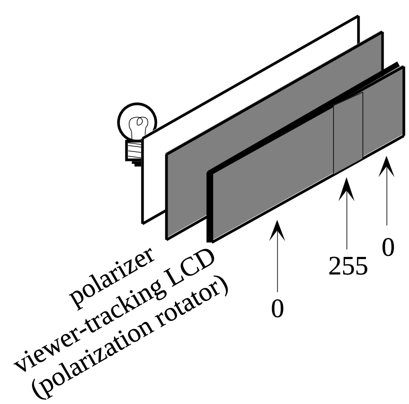

Figure 6. LCD polarization switch

3. VIEWER TRACKING FOR AUTOSTEREOSCOPIC DISPLAY

In order that the viewer may move freely from side to side, the "zone of +45° light" has to move so that its real image (focused by the viewing lens) falls at the location of the viewer's right eye. That location may be determined by a video camera plus image processing software. Our system consists of a simple black-and-white CCD camera located just below the output LCD screen, with low-level illumination coming from above the viewer. The video output is directed to an SGI O-2 computer that is running a face-locating program consisting of a neural net system that has been trained on hundreds of faces.[14,15] The output is a numerical report of the horizontal location of every right eye that is identified by the system. The system can acquire and track from one to three viewers at a time. During acquisition, the system runs at about four frames per second, and requires from two to four frames of processing delay to locate each viewer. When tracking two viewers, it operates at about 56 frames per second, slowing down to about 25 frames/second during rapid head movements. The process slows down roughly in proportion to the number of faces being tracked, so that the locations each of three viewers is usually updated about thirty times per second. The system uses a prediction algorithm based on recent speed and acceleration to determine where to look for the faces next. Thus, as long as the viewers are making somewhat smooth movements (no abrupt changes in direction), the speed of movement is not limited. However, the system will sometimes “lose” the viewers if they make sudden or jerky movements.

The reported viewer location coordinates are then used to create a pattern for display on the viewer-tracking LCD. Typically, the pattern is a narrow vertical bar centered at the column number corresponding (by taking the camera geometry into account) to the location of the viewer’s right eye. That part of the viewer-tracking LCD then transmits +45° light to the display system, for delivery to the viewer’s right eye. The rest of the viewer-tracking panel remains in the “off” condition, transmitting –45° light to the remainder of the viewing zone, including the viewer’s left eye. If the tracking system incurs errors, the right eye will see the correct view as long as the vertical bar is wide enough to accommodate the viewer’s right eye even if the center of the bar moves somewhat erratically. If the tracking system loses track completely, then both eyes see the left eye view, and stereopsis briefly vanishes (often undetectably so).

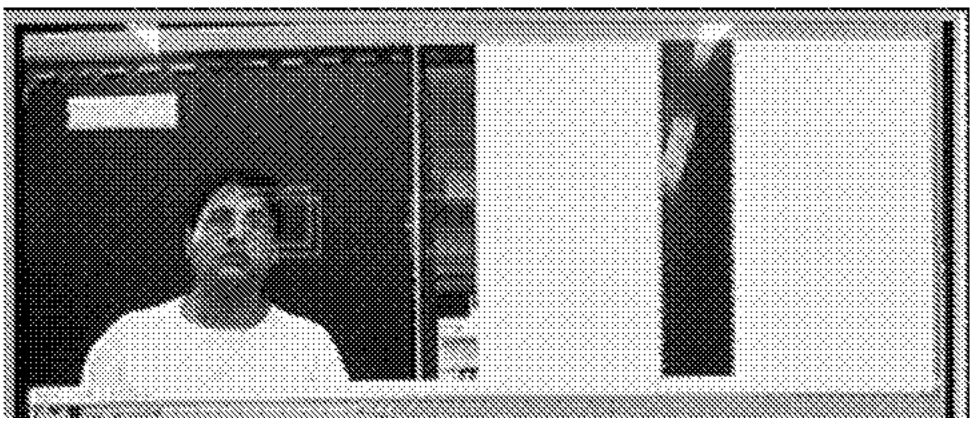

Figure 7. On the left, a viewer is being tracked, and a bounding box created around his left eye. On the right appears the video drive to the polarization-switching screen.

4. CHARACTERISTICS OF THE DISPLAY

The primary goals of the display design were 1) high quality autostereoscopic presentation (high acuity, contrast, reliable stereopsis), 2) immediacy of presentation (the central plane at the front surface of the display) and 3) accommodation of multiple viewers of arbitrary locations. Because the image is directly viewed on an LCD screen, the image quality (resolution and contrast) is quite high. Of course the vertical resolution is halved by the spatial multiplexing method, but the constantly-improving pixel count of LCD panels offers some relief from this problem. The panel can be located either before or after the final viewing lens of the system, and placing it on the viewer’s side offers the maximum of access. Of course the interaction space straddles the LCD screen, so that only half of it is available for co-located haptic displays for example, but even so the sense of immediacy is quite high. And because the viewer-tracking system is reasonably fast and accurate, several viewers can indeed be accommodated simultaneously, although the slowdown with three viewers is still noticeable.

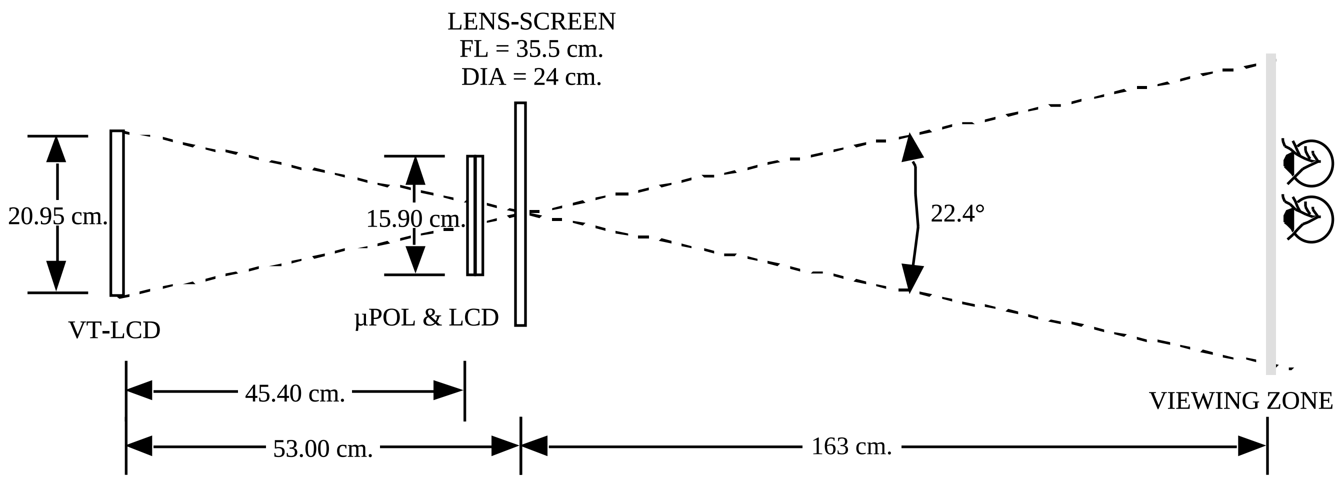

Figure 8. Diagram of prototype display.

A prototype display has been assembled with the optical layout of Fig. Eight. The micropolarizer and LCD sandwich is a VRex Model 1000 overhead projector unit.[16] Its micropolarizer layer is facing the illumination, and separated from the viewer-tracking LCD screen by a distance that permits it to be illuminated with the divergence needed to accommodate the distance between the micropolarizer array and the LCD pixels (normally the distance between the unit and the lens of an overhead projector). The viewing lens is downstream of the micropolarizer array & LCD unit, and has a focal length chosen to produce a real image of the viewer-tracking LCD at the intended viewing distance, about one meter. The viewing lens is a Fresnel lens for convenience, although its faceted structure produces some moiré patterns with the LCD pixels. The viewer-tracking LCD is simply a 26 cm. (10.25") diagonal color LCD screen—a black-and-white screen would be much more efficient in its use of light. The combined optics produced a angular viewing zone width of 24°, or a linear width of 42 cm, enough for two viewers at a time.

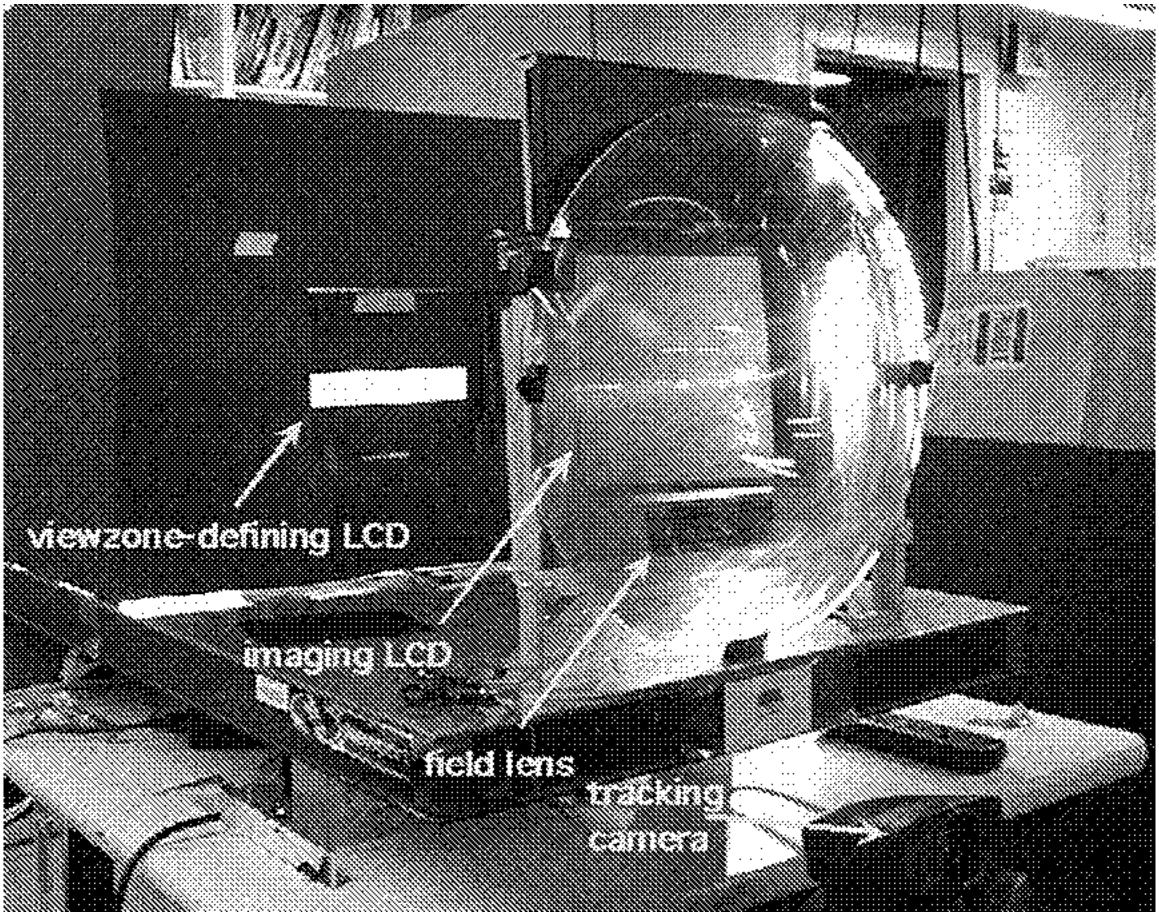

Figure 9. A view of the prototype micropolarizer-based autostereoscopic display.

Viewer acquisition is still an uncertain process, however, and there is considerable improvement of the software remaining to be undertaken. Happily, face tracking is a problem that is under attack in many corners of the machine vision world, and we stand ready to benefit from that wider research. A more stubborn problem, one that compromises both the accessibility of the image and the freedom of viewer location, is the requirement that the viewers be more or less at a predetermined distance from the display. The intended viewer locations are all at the surface defined by the real image of the viewer-tracking LCD, as focused by the output viewing lens or any equivalent optical system. This is, of course, a problem shared by most autostereoscopic display systems, and no satisfactory solution has been discovered, especially when multiple viewers at multiple distances are contemplated.

Output image size has been limited to 200 mm diagonal by the availability of commercial micropolarizer screens. However, new fabrication methods promise to accommodate newer generations of larger LCD screens. The micropolarizer is physically separated from the liquid crystal rows by the thickness of the glass panels involved, which produces some parallax effects that have to be carefully anticipated. We imagine that someday the micropolarizer may be placed inside the panel, perhaps integrated with the color filters, but this remains an engineer's dream.

5. FURTHER RESEARCH

The present system, which we have dubbed "Maxwell-like," is skeletal in its optical design and implementation. As such, it requires rather large LCD screens, notably for the viewer-tracking LCD if a wide viewing zone is to be afforded. A more complex "telescopic" system might allow the use of smaller LCDs, and perhaps a smaller footprint of the display as a whole. Other multiplexing schemes remain to be considered, but the particularly high visual quality of a directly-viewed LCD screen image recommends it very highly as a central design point.

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