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The use of computer graphics rendering software in the analysis of a novel autostereoscopic display design

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Abstract

Computer graphics ‘ray tracing’ software has been used in the design and evaluation of a new autostereoscopic 3D display. This software complements the conventional optical design software and provides a cost-effective method of simulating what is actually seen by a viewer of the display. It may prove a useful tool in similar design problems.

1. Computer graphics ‘ray tracing’

In computer graphics the term *ray tracing* is used to describe a particular method of image rendering[1]. A description of a three dimensional model is entered into the computer. A centre of projection and a window on an arbitrary view plane are selected. A ray is fired from the centre of projection through each pixel in the window. The colour of the first object intercepted by the ray is assigned to that pixel. Secondary rays may be fired from the intersection point to simulate shadowing, reflection, and refraction; this allows the simulation of transparent object, surface reflections and materials with different optical indices. Multiple rays may be fired through a pixel and the resulting colours averaged to ameliorate aliasing artefacts in the resulting image (Figure 1).

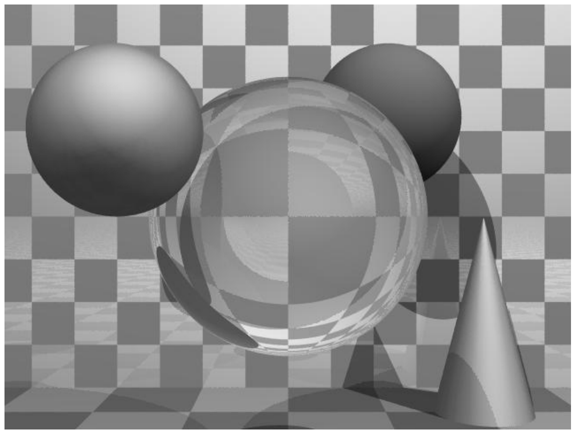

Figure 1: an example ray traced image. One sphere is transparent and refractive. The rear plane is semi-reflective.

Ray tracing, in the computer graphic sense, consists, essentially, of tracking photons backward from the eye to the light source(s). As such, it provides a tractable solution to the problem of determining the illumination of all surfaces in an image. It has limitations. It cannot, for example, handle diffuse inter-reflections between surfaces. It is, nevertheless, widely used in the special effects industry and it has proven useful in the design of a new autostereoscopic display device.

2. The autostereoscopic display

The display is a device which allows a viewer to see a different image with each eye, providing stereoscopic perception. Full details of the display may be found in Moore *et al*[2] and Dodgson *et al*[3,4]. It is an unusual display in that the viewer observes a CRT through an optical system, rather than directly (as in a conventional TV) or projected on a screen (as in a video projector).

The display consists of two superimposed optical systems (Figure 2). One can be thought of as a compound lens casting an image of the CRT to a plane in space. The other consists of an active shuttering element as close as possible to the front principal plane of the compound lens, and a further lens at the position of the CRT image. The second system can be thought to cast an image of the shutter into the space in front of the display. This image of the shutter is called the *eye box*. Consult references 4, 7 and 8 for more details.

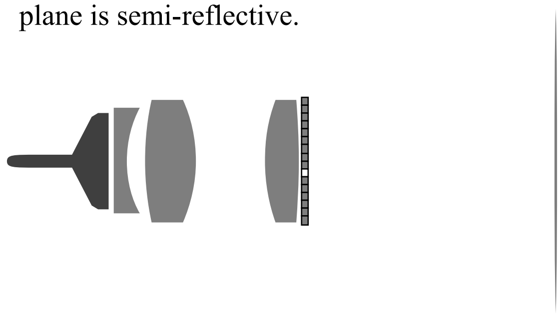

Figure 2: the basic display. CRT on left, compound lens in centre, active shutter to its right, front lens (Fresnel) at right.

In practice, no image of either shutter or CRT is actually cast onto any surface. The viewer observes the CRT face plate through the entire optical system, but has the illusion that the viewed image is displayed on the front lens element. The combination of a fast CRT with the active shutter enables the display to provide a different image to each eye, giving stereoscopic perception.

The original design for the display used a Fresnel lens as the front element. During development of the 50" version of the display[4] it became desirable to replace this lens with a mirror (Figure 3). One of the authors (JRM) experimented with a large (1m radius) spherical

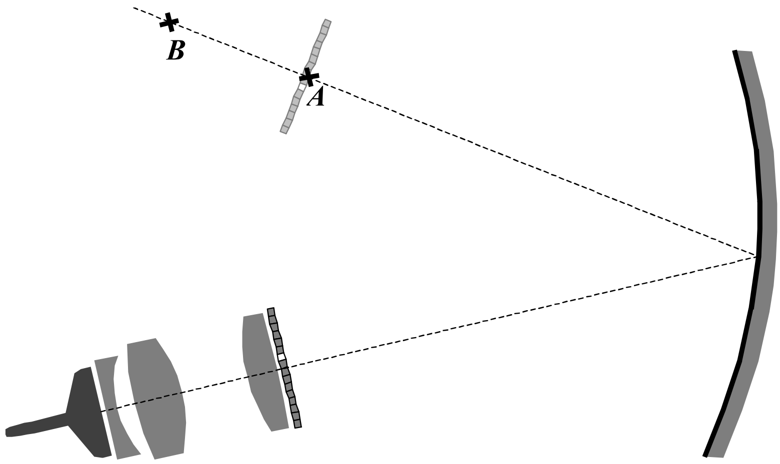

Figure 3: the proposed display. At bottom, CRT, compound lens and shutter. At right, curved mirror. At top, ideal location of eye box. ***A***: eye point for images in Figure 5; ***B***: eye point for images in Figure 6.

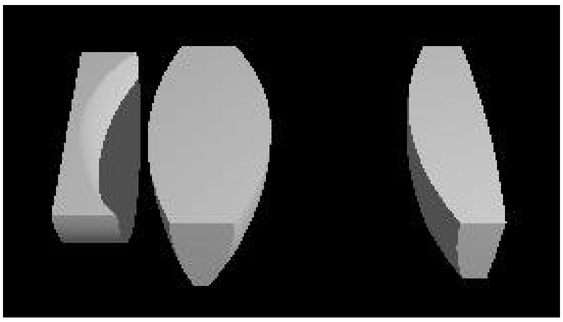

Figure 4: the lens array modelled in CSG and cut in half to show the cross-sectional profiles.

mirror, viewed off-axis. He observed peculiar distortions in the shutter image. This led him to propose that an ellipsoidal mirror might improve the quality of the 3D image. This ellipsoid would have one focus at the shutter's centre and the other at the centre of the shutter's image in space.

The experiments with the spherical mirror showed that the observed image on the CRT face was distorted by the mirror, but that this could be corrected by providing a compensating distortion on the CRT itself. However, the spherical mirror caused severe warping at the eye box of the shape of the view segments of the shutter. It therefore became necessary to ascertain whether the proposed ellipsoidal mirror would cause significantly less warping at the eye box without significantly increasing the distortion of the CRT image.

3. Method

Models of the compound lens elements (Figure 4) and mirrors were constructed using the technique of Constructive Solid Geometry (CSG)[1,5]. Images were rendered using the free ray tracing software *Rayshade*[6]. A grid image was placed in the position of the CRT face plate and images were ray traced with the eye point placed at the ideal distance, looking at the mirror. These showed what a viewer would see through the optical system, when standing at the ideal distance (Figure 5). They illustrate that the distortion is similar for both cases, allowing both to be corrected in the same way, by shape correction on the CRT.

A second set of renderings was then made (Figure 6), with the grid placed at the active shutter position and the eye point placed some distance further from the mirror than the ideal distance (the reason for this is explained by Dodgson[7,8]). For correct functioning of the display it is necessary for vertical lines on the shutter to remain reasonably vertical when viewed from positions such as this. The spherical mirror causes gross deviation from the vertical, closely matching observations of the experimental display's behaviour, while the ellipsoidal mirror causes minor, and acceptably small, deviation from the vertical indicating that an ellipsoidal mirror would be an improvement over a spherical mirror.

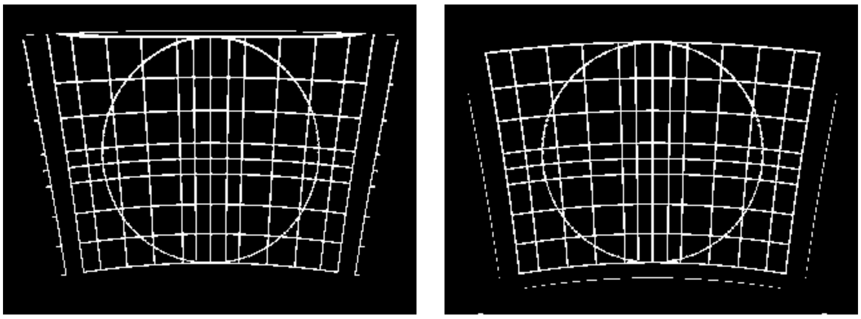

Figure 5: the CRT as seen by the viewer in the mirrors (viewer at ideal distance). Left: spherical, right: ellipsoidal. The image on the CRT is a grid with finer spacing in the centre and a superimposed circle.

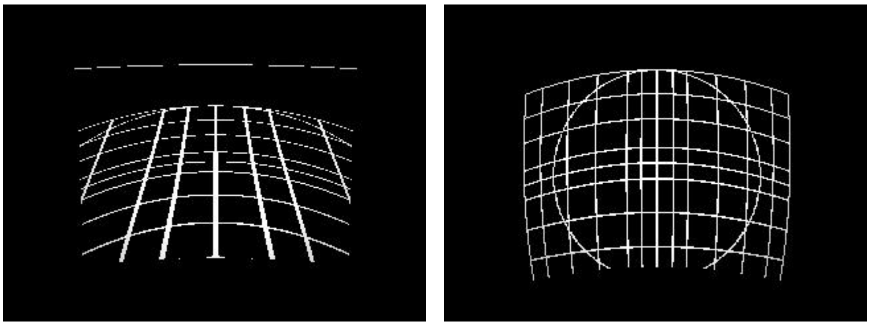

Figure 6: the shutters as seen by the viewer in the mirrors (viewer at $^{4}/_{3} \times$ ideal distance). Left: spherical, right: ellipsoidal. In this case, the vertical lines in the grid need to be as near vertical as possible, which they patently are not in the left hand image.

4. *Further investigations*

Images of both shutter and CRT were taken from a variety of points in space, both on- and off-axis, to ascertain the extent of the distortion in both spherical and ellipsoidal cases. Following on from this, detailed design and evaluation of the optical system was carried out using a conventional optical design tool (Code V)[9].

More recently, it became necessary to investigate the behaviour of the display at, and near, the ideal distance. The computer graphics ray tracer has again proved useful, allowing simulation of the effects seen by an actual observer. The results of this simulation can be used to guide decisions made in the conventional optical design software. This investigation has greatly improved understanding of the behaviour of the practical, as opposed to the theoretical, display device.

5. *Discussion*

Computer graphics ray tracing uses the same ray-object intersection calculations as lens design. The differences in the two methods are:

(a) In computer graphics it is necessary to trace the ray through every pixel, regardless of whether or not it is likely to hit anything. In lens design, it is important to find the rays which only just pass through an optical system, without generally caring about rays which miss the system entirely.

(b) The output of computer graphics ray tracing is an image showing what the eye would see from a particular location. The output of lens design is a plot of the optical system showing the important traced rays.

It is important to note that the computer graphics ray tracing software is accurate to the floating point accuracy of the computer being used. A carefully-written computer graphics ray tracer should have roughly the same fidelity as a optical design system running on the same hardware.

The images resulting from this work gave the designers a better intuitive idea of the design issues involved. However, computer graphics ray tracing can only be used as a tool in designs where the viewer observes a screen or other object(s) through an optical system. It cannot replace conventional lens design, but provides a cost-effective additional tool. Recent releases of popular optical design software[9,10] incorporate the type of rendering which we achieved using freely available software.

6. Summary

Freely available, free, computer graphics ray tracing software has been used in the design of a particular display device. It complements the use of conventional optical design software. Its utility lies in its ability to simulate what is seen by a viewer looking into the optical system. The authors commend its use in similar design problems.

7. Afterword

A careful reading of reference 4 will reveal that the final display used a mirror with spherical cross-section, despite the problems highlighted by our experiments. The decision to use a spherical mirror was taken for cost reasons: the extra accuracy of the ellipsoidal mirror was not thought to justify the increased cost and difficulty of manufacturing an ellipsoidal rather than spherical mirror.

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