RANDOM HOLE DISPLAY: A NON-UNIFORM BARRIER AUTOSTEREOSCOPIC DISPLAY

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ABSTRACT

A novel design for an autostereoscopic (AS) display is demonstrated featuring a randomized hole distribution parallax barrier. The Random Hole Display (RHD) design eliminates the repeating zones found in regular barrier and lenticular autostereoscopic displays, enabling multiple simultaneous viewers in arbitrary locations. The primary task of a multi-user AS display is to deliver the correct and unique view to each eye of each observer. If multiple viewers see the same pixels behind the barrier, then a conflict occurs. Regular barrier displays have no conflicts between views for many viewer positions, but have significant, localized conflicts at regular intervals across the viewing area and when viewed at different distances from the display. By randomizing the barrier pattern the RHD exhibits a small amount of conflict between viewers, distributed across the display, in all situations. Yet it never exhibits the overwhelming conflicts between multiple views that are inherent in conventional AS displays. With knowledge of user locations, the RHD presents the proper stereoscopic view to one or more viewers. It further mitigates viewing conflicts by allowing display pixels that are seen by more than one viewer to remain active by optionally blending the similar colors of desired views. Interference between views for random hole barriers and for a conventional regular barrier pattern are simulated. Results from a proof-of-concept Random Hole Display are presented.

***Index Terms*—** Three-dimensional displays, stereo vision, computer graphics, computer displays

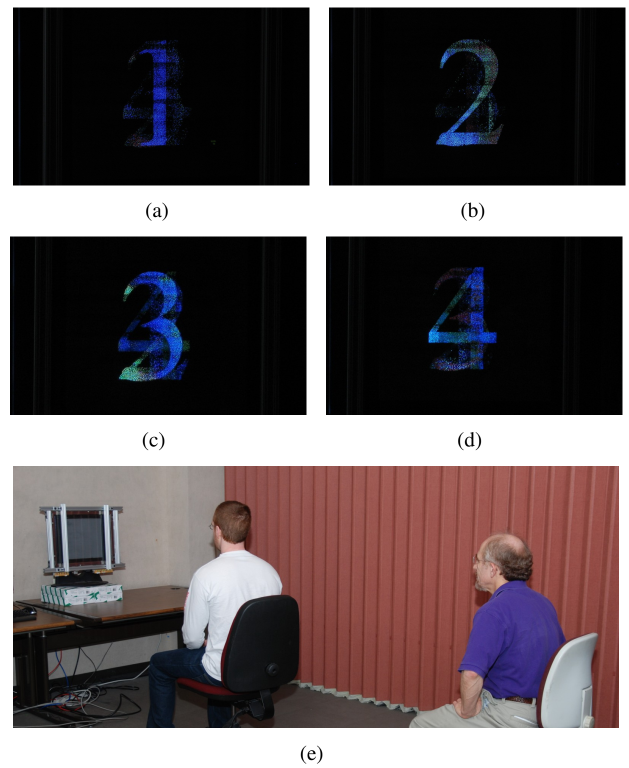

Fig. 1. Photos of four simultaneous views of the Random Hole Display, at (a, b) 1.5m and (c, d) 3m from the display, the two stereo viewing positions shown in (e).

1. INTRODUCTION

The most common type of multi-view display is stereoscopic, which presents different images to the left and right eyes of a viewer to enhance 3D perception. Stereo display is often accomplished using eye wear with passively polarized lenses or rapidly alternating shuttered glasses. However, users are burdened with encumbrances that can block eye gaze or cover their face. Autostereoscopy is a method of presenting stereo imagery to a viewer without the need for special glasses. There are three basic types of autostereoscopic (AS) display: holographic, volumetric, and parallax. Most commercial AS displays are parallax, using either barriers or lenticular sheets, emitting different two-dimensional images across the viewing field.

With regular barrier, multi-user AS displays, untracked users must remain in certain viewing areas or they will see incorrect imagery or the same imagery as other viewers. In AS display systems with user tracking, multiple viewers are usually not supported because individual display pixels will be seen from multiple views. These visual conflicts are localized and can cover large areas of the display, depending on the viewer positions, because of the regular barrier pattern. This interference between views is a form of aliasing.

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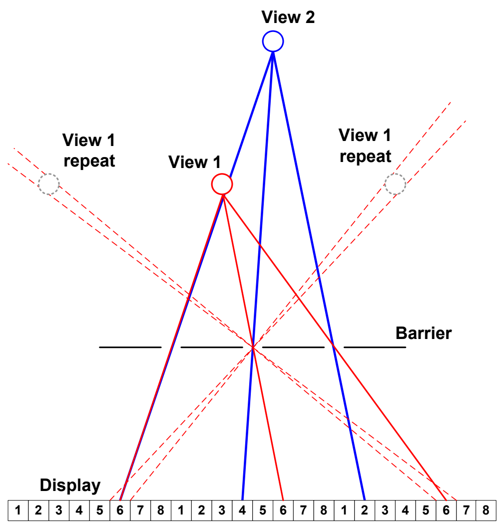


Fig. 2. A top down diagram of an 8 view, regular barrier AS display showing two viewing positions.

Aliasing is a long recognized problem in computer graphics, generating numerous artifacts such as jagged edges and Moiré patterns. Solutions include pre- and post-filtering images and supersampling. Although filtering methods for antialiasing in AS displays have been proposed [1], these operate on image quality and depth-of-field rather than between views. Supersampling is not possible because the barrier pattern fixes the sampling rate of the underlying display.

A different solution to the aliasing problem is stochastic sampling, which replaces aliasing with high frequency noise that is less objectionable to the human visual system [2]. There are many classes of stochastic sampling, but an immediately useful form is the Poisson disk distribution, which enforces a minimum distance between randomly placed sample points. This ensures uniform distribution over the larger pattern and trades off perceptually difficult low and mid frequency noise for less troublesome high frequency noise [3].

This paper introduces the Random Hole Display (RHD), a parallax barrier AS display that uses a barrier with a Poisson disk pattern of holes. The RHD design offers a number of capabilities that are not found in most existing AS displays, including display for multiple users in arbitrary viewing positions. By randomizing hole distribution in the barrier, visual conflicts between views are distributed across the viewing area as high frequency noise, and can be minimized by changing the parameters of the barrier design.

2. BACKGROUND

Parallax AS displays, based on barriers or lenticular sheets, operate by occluding certain parts of an image from a particular viewing direction while making other parts visible. They provide different imagery to the left and right eyes of a viewer, allowing for 3D perception of a scene. This is commonly achieved by dividing the horizontal resolution of a display surface behind the parallax barrier among several views.

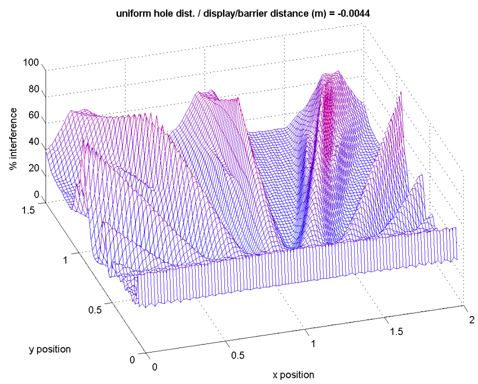
An example of a parallax barrier system is the NYU autostereoscopic display [4], which uses an active light blocking shutter that changes in response to a tracked user head position. The system generates the barrier pattern in front of a display surface so that each alternating stripe is seen by a different eye. The reverse approach is taken with the Varrier display [5], where the barrier is a fixed pattern and the sets of backing pixels visible for the left or right eye are computed based on the tracked user position. These displays can provide high quality stereo views, but do not support multiple simultaneous viewers.

To support multiple viewers, some AS displays provide many views to allow for several possible viewing positions. This allows a single viewer to experience correct 3D views from various positions. Examples include the MERL 3D TV system, which uses projection display with lenticular elements [6], and commercial systems such as Philips 3D displays [7].

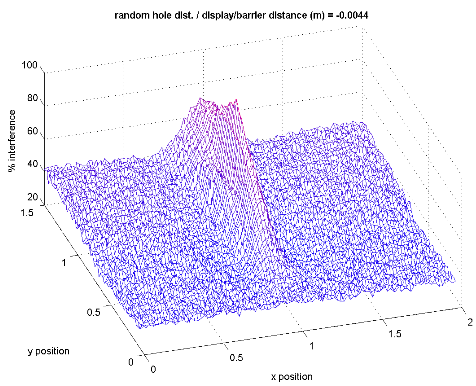
To preserve horizontal resolution, multiview AS displays have a limited number of distinct views, typically eight to ten. AS display requires sizing individual views to the scale of the interpupillary distance of a user, approximately 6cm. At the optimal distance where this spacing occurs, the maximum width of the display's views is approximately half a meter. This leads to two fundamental problems for groups of users viewing such an AS display.

Figure 2 depicts a regular barrier AS display with 8 views and two viewing positions. Two monoscopic views are shown for clarity, but stereo viewers experience the same problems. A viewer at position 1, at the optimal distance from the display, will see all of the pixels labeled 6. Due to the regular pattern of the barrier, this view repeats in front of the display at regular intervals in each viewing zone. Any other viewer must be restricted from entering any of these repeat areas or they will see the same output as the viewer at position 1. This severely limits the lateral movement and potential viewing positions for additional viewers.

The second problem occurs when two viewers are at different distances from the display The viewer at position 2 sees pixels labeled 6, 4, and 2 through adjacent barrier holes. These visible pixels occur at a different period than the pixels visible from position 1. This leads to interference between views, where the viewer at 2 will see part of viewer 1's imagery in certain regions of the display. The superposition of these pixel sets leads to a beating pattern of pixels seen by both users simultaneously, no matter what their lateral position. This restricts multiple users to approximately the same distance from the display.



(a)



(b)

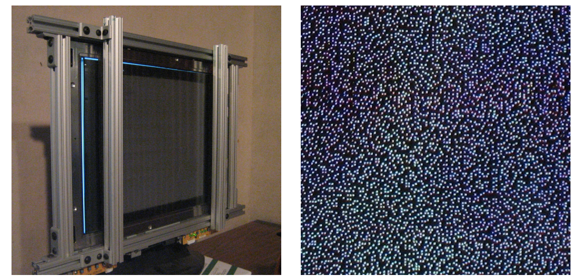
Fig. 3. Interference between two stereo viewers, one fixed at [1,1] and the other at the plotted [x,y] position: (a) regular barrier of a conventional AS display, and (b) RHD barrier.

3. BARRIER SIMULATION

To measure the interference between views, conventional and random hole barrier AS displays are simulated. The following simulation results are based on parameters of a desktop-scale AS display, including pixel count, display size, barrier hole size, and number of holes. The uniform barrier of the conventional display is compared to a barrier with jittered hole positions (an approximation of Poisson disk distribution) for a display scan line. The display is fixed in virtual space at (1m, 0m), with one stereo viewer centered one meter from the display, at (1m, 1m). The interference between views (measured as % of visible pixels seen by multiple views) of the fixed user and another user at uniformly distributed positions every 0.02m over a 2m wide by 1.5m deep area in front of the display is computed and shown in Figure 3.

Near the display, interference rises equally as the minimum viewing distance is approached. The same pixel is seen by both eyes of a single viewer through neighboring holes and the interference is caused by this near viewer alone. Spines representing areas of high interference are spaced at regular angles from the display. This is the zoning effect fundamental to regular barrier AS displays. When two stereo viewers are located in the same zone, interference is very high. In between these spines, view interference is very low, as the second stereo viewer is in a different viewing zone.

The experiment is repeated with a random hole barrier, and all other parameters are kept the same. The expected spine of interference when the two stereo viewers are on the same viewing axis remains. Elsewhere, the random distribution of barrier holes eliminates viewing zones and distributes the interference as noise across the viewing area.



(a) (b)

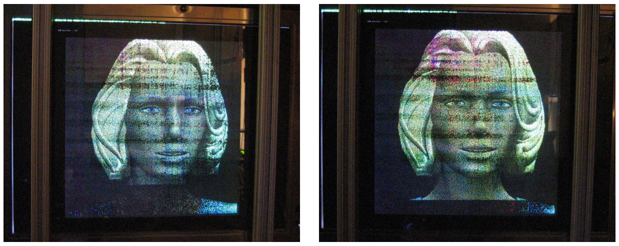
Fig. 4. Views of the RHD prototype: (a) the barrier fixed in front of the LCD panel, and (b) a close up of part of the actual barrier in front of the fully lit display panel.

4. SYSTEM DESIGN

The prototype Random Hole Display, shown in Figure 4, uses a plastic barrier separated from a 100dpi 20” flat panel LCD display by a 1/4” glass spacer. The barrier pattern was laser cut with a Poisson disk distribution of holes, each 1/100” square, with 1/9th hole fill factor and a 2/100” minimum spacing constraint. The pattern covers a 10” x 10” area with 1000 x 1000 backing pixels.

The prototype is calibrated for a particular viewpoint with a pair of high resolution cameras at the desired stereo viewing location. For a flat panel display with physically discrete subpixels, each color channel is calibrated separately. For a h x v resolution display, an optimal calibration method would use a binary coding (such as a Gray code) to uniquely identify display pixel visibility with only ($\log_2 h + \log_2 v$) images. However, lighting the display with bright regions leads to edge detection issues in the camera. A compromise between speed and sensitivity is accomplished using a line sweep in the horizontal and vertical direction, for a total of ($h + v$) images. To uniquely identify each visible display pixel, all camera image pixels with values above the specified threshold are labeled with the value of the display scan line. This generates a mask of all visible display pixels from this camera position.

The masks produced by this calibration are passed to the renderer along with the desired imagery for each view. By



(a) (b)

Fig. 5. Photographs of simultaneous (a) left and (b) right eye views of a 3D model.

comparing masks for each view, the visibility of each display pixel is determined. Some pixels are seen by only one view, and so the corresponding imagery is displayed as usual. Other pixels are not seen by any view and remain black. Pixels that are seen by multiple views make up the view interference. A pixel with similar colors in all of the masked imagery remains active, but one with different contributing color values is set to black.

5. RESULTS

The prototype Random Hole Display is able to present several simultaneous views, each directed to arbitrary locations in the viewing area. Figure 1 shows photographs from four viewing positions, corresponding to the two stereo views of the users in (e). The expected interference between views is noticeable, but the unique view content is easily distinguished. In typical usage, two stereo views are shown, but the RHD is capable of presenting four monoscopic views to any location as well. Stereo views have been calibrated at various distances from the display, as close as 50cm and as far as 4m. Simultaneous stereo views in many different viewing positions have been tested, with views at the same distance from the display, and varying separations, both laterally and from the display.

Limited user testing has shown that viewers are able to judge the perceived depth of simple geometric primitives relative to the display surface, both in front and behind. They are also able to fuse stereo imagery of more complex scenes, such as the 3D model in Figure 5. Manufacturing artifacts in the prototype barrier lead to some perceptibly darker bands, but multiple simultaneous views from arbitrary positions remain distinct.

6. CONCLUSIONS AND FUTURE WORK

The Random Hole Display allows for multiple stereo viewers in arbitrary locations, without the restrictions of conventional AS displays on viewing positions. By randomizing the barrier hole pattern, the aliasing interference between views is replaced with high frequency noise, which is less visually objectionable than large regions of conflict. This interference is further mitigated by comparing the image pixels and optionally displaying pixels seen by multiple views. The current prototype system uses view masks from static calibration positions. Future versions of the RHD will track users and generate masks for every viewing position in each frame, using a real-time masking technique similar to the Varrier approach [5]. Higher pixel density displays, such as QuadHD resolution monitors, and camera-based user eye tracking will allow for encumbrance free AS viewing with high resolution for multiple viewers. The RHD concept may also be combined with an active barrier, allowing optimal hole density for various numbers of viewers.

7. ACKNOWLEDGEMENTS

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