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Paprocki, Martin Marko; Krog, Kim Srirat; Kristoffersen, Morten Bak; Kraus, Martin

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Software-Based Adjustment of Mobile Autostereoscopic Graphics Using Static Parallax Barriers

Martin Paprocki
School of Information and Communication Technology, Aalborg University, Denmark
mpapro09@student.aau.dk

Morten Bak Kristoffersen
School of Information and Communication Technology, Aalborg University, Denmark
mkr08@student.aau.dk

Kim Krog
School of Information and Communication Technology, Aalborg University, Denmark
kkrog08@student.aau.dk

Martin Kraus
Department of Architecture, Design and Media Technology, Aalborg University, Denmark
martin@create.aau.dk

ABSTRACT

We show that the autostereoscopic display of stereoscopic images using a static parallax barrier can be improved by adapting the rendering to the angle under which the user is looking at a mobile display; thus, ghosting artifacts and depth reversals can often be avoided even if the user tilts the mobile device. Instead of moving the barrier itself to compensate for a misplacement of the viewing zones in relation to the user, we employ dynamic pixel column shifts to provide a similar compensation in software. This requires a parallax barrier where each section covers two pixel columns at a time instead of one. The proposed method has been implemented using OpenGL shaders and a parallax barrier that was designed for a display of exactly half the resolution of the employed display. Technical tests showed a good separation of the left and right images for viewing angles of up to $\pm$ 30°. Preliminary user tests indicate that an improvement in the stereoscopic experience can be achieved.

Categories and Subject Descriptors

I.3.7 [**Three-Dimensional Graphics and Realism**]: Virtual reality

General Terms

Algorithms

Keywords

Autostereoscopy, display, parallax barriers, adaptive interface, mobile device, ghosting, context aware interface, GPU

1. INTRODUCTION

In recent years mobile consumer devices started to adopt autostereoscopic displays. Although autostereoscopic displays with static parallax barriers are a low-cost and competitive solution for displaying stereoscopic images, they are quite limited since they have to be viewed from a specific position. Displaying the stereo effect correctly requires the viewer to remain within a relatively narrow viewing angle, as well as maintaining an optimal viewing distance to the autostereoscopic display [12]. If these conditions are not fulfilled, ghosting or reversed stereo depth will deteriorate the stereoscopic effect. The ghosting is caused by leakage from the left eye image to the right eye image and vice versa. The reversed stereo depth occurs if the left image is seen by the right eye and vice versa [11]. In some cases this makes it impossible to obtain the correct stereoscopic effect, e.g., in game applications where the device is tilted as a part of the gameplay. In such a situation, one would from time to time see the correct, a mixed and the reversed stereoscopic image. Presumably, this results in an uncomfortable experience due to the varying depth perception.

To overcome some of the limitations of static parallax barriers, we present a low-cost software-based improvement of autostereoscopic displays using dynamic pixel column shifts (see Figure 1), which employs static parallax barriers with two pixel columns per section of the barrier (see Figure 2). A test application was implemented demonstrating how an OpenGL application can alter the pixel arrangement based on gyroscope and accelerometer data in order to compensate for varying viewing angles. In the next section, related work is summarized followed by Section 3 describing our method along with an implementation of it. In Section 4, the technical test is discussed and in Section 5, a calibration scene is described and Section 6 reports results of a preliminary user study. Conclusion and future work are presented in Section 7.

2. RELATED WORK

Consumer mobile devices with autostereoscopic displays include smartphones [7] and game consoles [8]. In addition, low-cost parallax barriers which can be added to a mobile de-

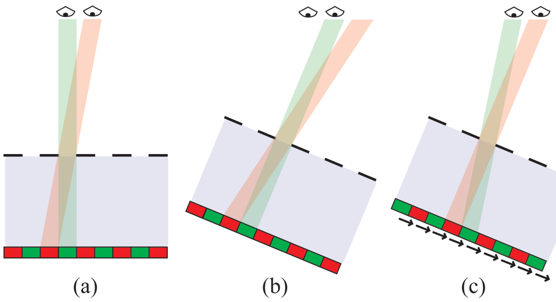

Figure 1: (a) Correct viewing angle for stereoscopy with a parallax barrier. (b) Misplaced eyes after tilting. (c) Corrected viewing zones by shifting the pixel columns.

vice without a built-in autostereoscopic display are available [2][10]. Solutions to some of the limitations of static parallax barriers have been proposed, although most of them are not purely software based. Perlin et al. [9] have demonstrated electrical parallax barriers with dynamic width, which adapt to the user by means of camera eye tracking. Recently, LG Electronics [6] has released commercial products using similar technology. Lanman et al. [5] have demonstrated content adaptive parallax barriers, which allow the barrier to show non-binary opacities. Most similar to our work is a patent by Grossman [3] for an autostereoscopic display using a static parallax barrier. However, this method is limited to segments that are several pixels wide and include redundant image information.

3. ADJUSTING THE RENDERING

We assume that users look directly at the mobile device and keep their heads still while tilting the device. The rendering on the mobile device should then be adjusted to the angle between the user's viewing direction and the mobile device; otherwise the user's eyes move out of the viewing zones of the autostereoscopic display. The angular misplacement can be measured in several ways, for example by using head tracking or gyroscope and/or accelerometer data. In this work, we employ gyroscope and accelerometer data in order to keep the implementational and computational costs low.

We suggest adapting the rendering to the measured angle. Specifically, the parallax barrier [2] employed in this work requires an arrangement of alternating pixel columns of the images for the left and the right eye. If positioned correctly, the parallax barrier makes sure that each eye sees only the pixel columns of the corresponding image (see Figure 1a). If the device is tilted, however, pixel columns become visible that are intended for the other eye (see Figure 1b). As suggested by Ichinose et al. [4], we can solve this problem by shifting pixels column-wise in relation to the measured angle (Figure 1c). However, shifting pixel columns in discrete steps generates discontinuous changes of the rendering. To avoid this, an interpolation of the pixel column colours is used.

As the interpolation takes effect, the stereoscopic images would usually blend together, which would result in strong ghosting. However, we can avoid this problem with a screen

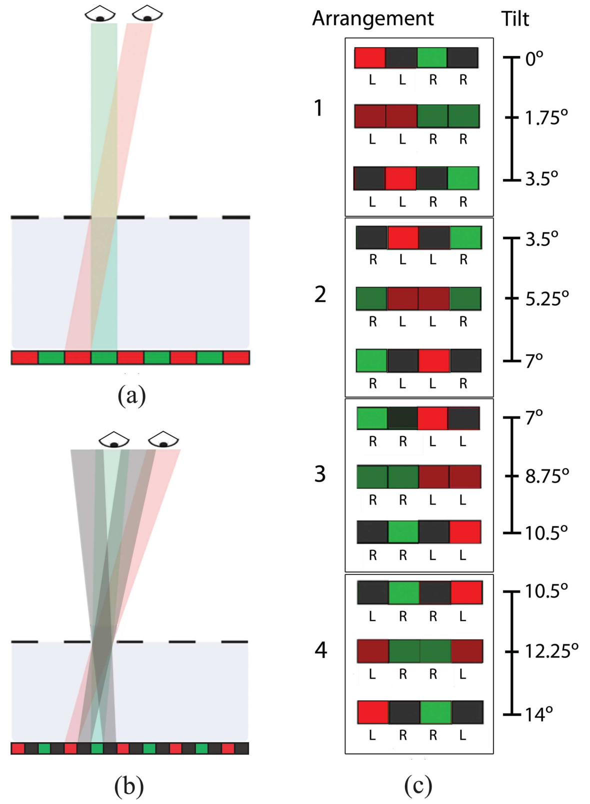

Figure 2: (a) Standard use of a parallax barrier. (b) Our use of a parallax barrier with a screen of twice the resolution. (c) The system of pixel column arrangements used to blend and shift pixel columns.

of twice the resolution of what the parallax barrier is made for (compare with Figures 2a and 2b) since this offers the possibility of starting with every second column being black (see Figure 2b). This way, the blending does not occur within the images themselves, but with the black pixel columns; thus, the images are kept separated. In our implementation (see Figure 2c), the baseline pixel arrangement is rendered with one column of pixels of the left image (red pixels labelled "L" in Figure 2c), one column of black pixels, one column of pixels of the right image (green pixels labelled "R" in Figure 2c) and one more column of black pixels. This baseline pixel arrangement is used for the correct viewing position, i.e., when the difference of the measured viewing angle to the optimal viewing angle is 0°. The baseline arrangement is also used for multiples of 14°. This particular value was determined through two types of tests for the particular parallax barrier [2] employed in this work. For other angles, four different pixel arrangements are used as illustrated in Figure 2c. The first pixel arrangement is used from 0° to 3.5° (= 14°/4). The angle within each pixel arrangement is normalized by a linear mapping to 0 to 1. The normalized angle controls the interpolation between pairs of pixel columns. For example, at 1.75° both pixels of each pair would have the same colour. At the point where the shift by one pixel is completed, i.e. at 3.5°, the first pixel arrangement stops, and the second pixel arrangement takes over. This shifts the image one pixel to the right. The third and

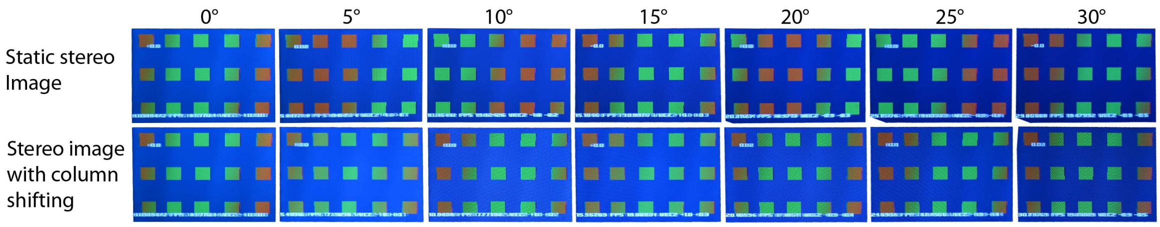

Figure 3: The two series with and without the column shifting.

fourth pixel arrangement are applied in the same manner. At 14° the first arrangement starts over again.

Due to the effect of the barriers and the interpolation of colours, the perceived intensity varies with the angle. To compensate for this variation, the intensity is increased in dependency of the normalised angle with the maximum increase at 0.5 and no increase at 0 and 1. Moreover, the angle lags behind if the rotation rate is high; therefore, a correction based on the rotation velocity is added to the measured angle predicting the actual orientation of the device.

4. TECHNICAL TEST

The setup for the technical test consisted of a test application on a fourth generation iPod Touch [1] running iOS 4.3.5 and a camera (simulating an eye) directed at it at a distance of 54.5 cm. To demonstrate how the solution performs, the iPod was rotated from 0° to 30° in steps of 5°. In each step a photograph was taken. Using a test scene with one camera lens reveals which one of the two left/right images or what mixture of those is visible and would be perceived by the user. Moreover, a video sequence was filmed to determine how fast one can rotate the device while still obtaining the correct image. This was done with the same setup and the rotation was performed manually.

Figure 3 shows the results from the technical test. At 5° the static stereo image (i.e. without pixel column shifts) has moved two-thirds across the screen to the right. Continuing the rotation results in various mixtures of the two images, which would result in strong ghosting artefacts. The series with pixel column shifting shows an approximately constant image from 0° to 30°. Thereafter the column shifting loses its impact. The video test focuses on the iPod's gyroscope rotation rate, where two roll velocities are taken as reference point. The velocities are $0.1\frac{\text{rad}}{\text{s}}$, which is rather slow, and $0.2\frac{\text{rad}}{\text{s}}$, which is a moderate velocity. At $0.1\frac{\text{rad}}{\text{s}}$, the column shifting had some trouble following the rotation but showed the correct image with a bit of flickering. At $0.2\frac{\text{rad}}{\text{s}}$, the column shifting fell behind and one-third of the wrong image shifted to the right during the clockwise rotation and the flickering increased as well.

5. CALIBRATION SCENE

When utilizing parallax barriers, one way to ensure high-quality stereo images with little or no ghosting in the viewing zones is to ensure that the pixel columns are only visible from the intended eye. This condition can be obtained by setting up a calibration scene, which in our case consists of red and green columns, with every other column being black, see Figure 4.

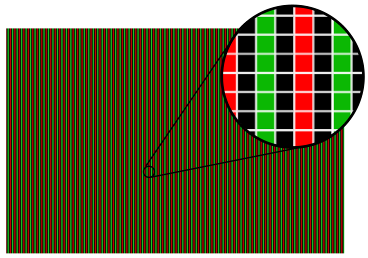

Figure 4: The structure of the calibration scene.

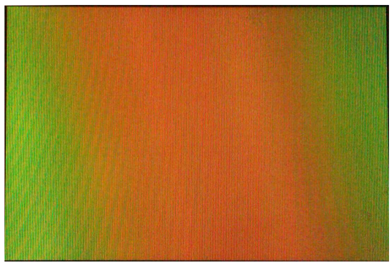

Figure 5: Photo of the autostereoscopic display showing the test scene used for calibration.

The calibration was set up such that the correct stereoscopic effect is restricted to the center of the screen (see the red area in Figure 5) as first tests showed that this resulted in a clearer stereoscopic effect at more comfortable distances when using the employed parallax barrier [2]. The calibration ensures a suitable ratio between the individual user's eye distance and the distance to the screen. Before using the actual application, the users are presented with the calibration scene and are asked to close one eye while positioning themselves so that the other eye sees the two colors covering half of the screen each. In this position, the user should then adjust the device such that one color is in the middle and the other is at the side, see Figure 5.

The calibration is verified by letting test subjects open only the previously closed eye and confirm that they see the inverse colours. After the calibration process is concluded and a proper distance between the user and the screen is found, the user can proceed to the actual application.

6. USER TEST

A user test was conducted to see whether users preferred the adaptive rendering over the non-adaptive rendering. A simple game was implemented which required the user to aim at a moving target with a small crosshair by tilting

Figure 6: Photo of the game used for the user test.

the mobile device. Behind the target, some textured, low-polygon 3D objects were placed to have some objects that the user could perceive in stereo (see Figure 6). A bar in the game consisting of green and red columns (similar to the calibration image) was included to simplify the calibration process. The test consisted of four parts:

1. Using a stereo viewer with perfect separation, it was tested whether the test subject could perceive stereoscopic images at all. Three sets of two images were used where each set consisted of a picture and the same picture in stereo. The test subject was required to correctly identify all three stereo images.
2. The test subject was shown the calibration image and was instructed how to calibrate.
3. The test subject tried two versions of the game, one with and one without adaptive content and was asked to tell which one he or she preferred. The user was given a limited amount of time with each version and the sequences were randomized between users.
4. After a re-calibration, the test subject was asked to try the versions again and was told to focus especially on the stereoscopic effect and then tell which one he or she preferred. The test subjects could switch between versions and had unlimited amount of time.

Table 1 shows the results of tests with 15 subjects. Half of the test subjects preferred adaptive stereoscopy, a fourth of the users preferred non-adaptive stereo and the last fourth could not see a significant difference between the two.

7. CONCLUSION AND FUTURE WORK

We have presented a novel method in autostereoscopy using software-based adjustments of graphics for static parallax barriers on mobile devices. We presented an adaptive display solution that features pixel column shifts with interpolation. A first user test indicates an enhancement of the users' perception of the stereo effect. The employed GPU shader is only a prototype solution. Its performance is very limited since it uses "discard" shader instructions. An improved version could use the same pixel arrangements but employ rendering to textures instead of "discard" instructions. This would save significant processing resources and could open the possibility of applying head tracking in combination with the current method. This way, the user could move the head without losing the stereoscopic effect as the head tracking would determine how to adapt the pixel arrangement.

Table 1: Number of test subjects and their preferences.

	1st evaluation	2nd evaluation
Adaptive shader	7	8
Non-adaptive shader	4	3
Undecided	4	4

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