Transparent Display Interaction without Binocular Parallax

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ABSTRACT
Binocular parallax is a problem for any interaction system that has a transparent display and objects behind it. A proposed quantitative measure called Binocular Selectability Discriminant (BSD) allows UI designers to predict the ability of the user to perform selection task in their transparent display systems, in spite of binocular parallax. A proposed technique called Single-Distance Pseudo Transparency (SDPT) aims to eliminate binocular parallax for on-screen interactions that require precision. A mock-up study shows potentials and directions for future investigation.

ACM Classification: H5.2 [Information Interfaces and Presentation]: User Interfaces – Interaction styles.

Keywords: Transparent display; Binocular parallax

INTRODUCTION
The usefulness of a transparent display is that it is transparent. In other words, the user can see through it, to look and interact with objects behind it. Combined with augmentation techniques, users will be able to interact with physical and virtual objects behind transparent devices in the near future. However, unlike the conventional opaque displays with which the user has to focus only on one object (the screen), the user has to look at objects at different distances from them with transparent displays. This causes binocular parallax. In this paper, we highlight binocular parallax as a problem that can cause usability issues, introduce a useful approach of quantifying this problem – ‘Binocular Selectability Discriminant’, and a possible solution – ‘Single-Distance Pseudo Transparency’.

BINOCULAR PARALLAX PROBLEM
Binocular parallax occurs because a person’s left and right eyes are separated and therefore see different images, with the focus determining how the two images are combined. When a person chooses to focus on the near object, the images are combined to create singular image for the near object, creating a duplicated and partially overlapping image for the distant object, and vice versa.

Such a parallax provides an important depth cue [1], but can cause a problem for an interaction system with a transparent display and objects behind it. For example, when a person places a finger on the transparent display for interaction with a behind object, the person has to focus either on the near finger or the far object, creating a duplicated image of the other that makes precise interaction difficult.

A simple experiment (Figure 1) was performed with two cameras separated by 7 cm (simulating eyes) with 45 cm from the fingertip to the cameras (simulating comfortable arm length interaction on a transparent display), and a 4 cm diameter Ping-Pong ball (simulating the bounding sphere of an object behind). In this configuration object distance as small as 30 cm caused significant parallax, rendering even basic interaction such as pointing difficult.

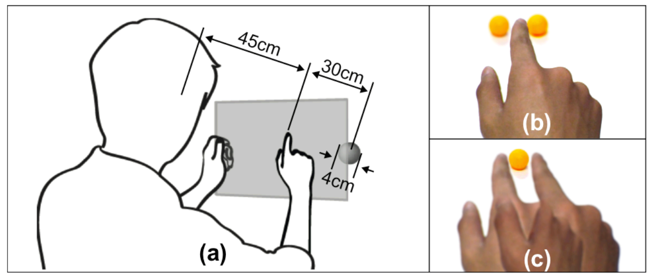

Figure 1: Binocular parallax can make interaction through a transparent display difficult (a). Images from left and right eyes are combined to create singular images for the fingertip (b) and the behind object (c).

BINOCULAR SELECTABILITY DISCRIMINANT
We define Binocular Selectability Discriminant (BSD), which UI designers can utilize to quantify binocular parallax and test whether binocular parallax will be problematic in their transparent display systems. The discriminant is based on a simple selection task, because the ability to select is often essential for higher level tasks.

In the simplified model (Figure 2), a user with an eye-to-eye distance of ‘L’ (~7 cm) views the transparent display from distance ‘D’ (~45 cm), and attempts to select an object with width ‘w’ and distance ‘d’ from the display by placing his finger on the screen. The rays fired from the eyes go through the fingertip and make duplicate images of the finger with distance ‘p’ apart. From similar triangles, p is Ld/D.

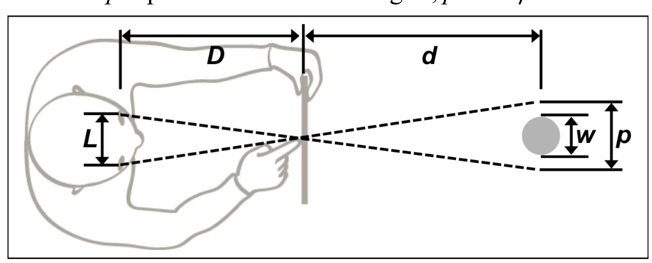

Figure 2: Diagram used for deriving Binocular Selectability Discriminant (BSD).

For selection to be possible, p must be smaller than w. So the discriminant writes:

$$\mathrm{BSD} \equiv \frac{w}{d} - \frac{L}{D}$$

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Higher BSD corresponds to easier selection (Figure 3a), BSD of 0 to barely possible selection (Figure 3b), and BSD of less than 0 to impossible selection (Figure 3c).

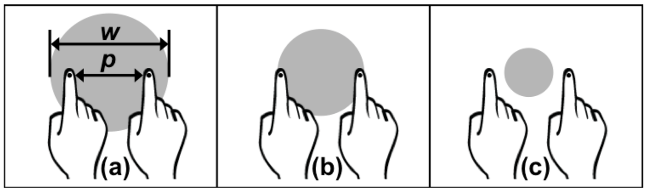

Figure 3: Easy to select (BSD>0) (a), barely able to select (BSD=0) (b), unable to select (BSD<0) (c).

The model simplifies many details, but is meaningful because it enables UI designers to make a first estimate of the viability of the most basic task in their particular systems. Depending on the size of an object to be selected and the distance from the transparent display to the object, it may be impossible to select the object, requiring a dedicated technique to overcome this problem and ensure usability. One such technique is introduced below.

SINGLE-DISTANCE PSEUDO TRANSPARENCY

Binocular parallax is caused by objects at different distances, so one solution would be to make everything the same distance away when it is a problem (BSD<0). Single-Distance Pseudo Transparency (SDPT) changes the transparent display's opacity to do just this. In SDPT, we assume that the size and the distance of an object to be selected are known. This is easily the case when objects are virtual [3], and can be achieved by scanning [2] and appropriately segmenting when they are physical.

When the object is big enough or distance is close enough such that selection is possible (BSD≥0), real transparency is maintained (Figure 4).

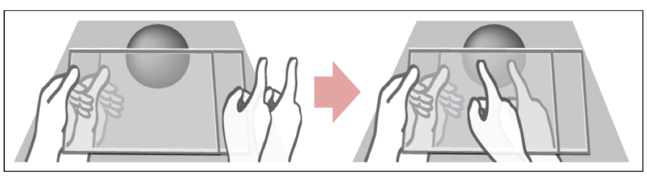

Figure 4: In Single-Distance Pseudo Transparency (SDPT), real transparency is kept when selection is possible despite binocular parallax (BSD≥0).

When the object is too small or too distant and therefore selection is impossible (BSD<0), the transparent display becomes fully opaque to block the view of the object as the fingertip approaches. It instead shows a representative head-tracked and distortion-corrected perspective render of the object (Figure 5) [4].

With SDPT the user can easily select a behind object without binocular parallax, because the object is transformed into a representative 2D image on the display surface. However, experiments are needed to quantitatively verify the merits and limitations of this technique.

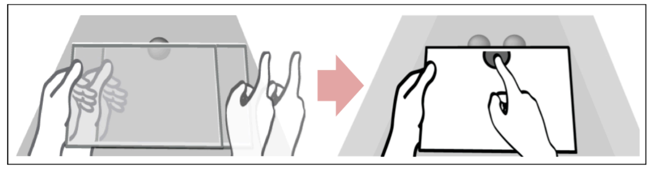

Figure 5: In SDPT, when selection is impossible (BSD<0) the screen turns opaque, displays a synchronized, head-tracked, perspective render of the object behind it, to eliminate binocular parallax.

MOCK-UP STUDY

To get an impression of how SDPT might work and set directions for future investigation, we conducted a mock-up study, without a transparent display, and with two interlaced OHP film sheets with 1 mm thick black vertical stripes, separated by 1 mm, printed (Figure 6a). When the stripes coincided, we could see the behind object (a white circle) through the vertical gaps (Figure 6b), and when horizontally slid (Figure 6c), the stripes filled the gaps and the films turned opaque, with the SDPT image patterned on the rear sheet (a red circle) showing (Figure 6d).

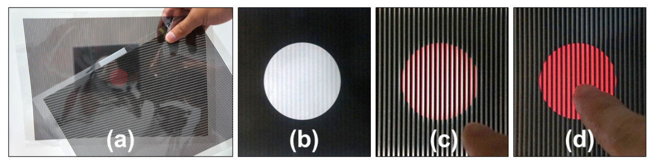

Figure 6: Mock-up study configuration (a), simulating real transparency (b), during transition in SDPT (c), and fully opaque in SDPT (d).

We positively confirmed that selection is unhindered with SDPT, but focal distance transitions were sometimes slow, laborious, and confusing, requiring further investigation.

CONCLUSION AND FUTURE WORK

Unlike the opaque displays we are familiar with, transparent displays are inherently susceptible to binocular parallax. In this paper, we suggest that binocular parallax is a problem to be solved. The quantitative measure (BSD) and a potential solution to the problem (SDPT) may help researchers notice this problem and approach it.

We will investigate binocular parallax by constructing detailed models dealing with more complex tasks. In addition, we will implement SDPT using an actual transparent display and perform experiments to quantitatively test its usability, concentrating on focal distance transition.

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