# Perceiving 3D from a 2D Mid-air Image

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Abstract

In this study, we aim to quantify the sense of depth and perceived position in mid-air images. In the experiment, the participants were instructed to indicate the nearest frontal point and zenith of both mid-air images and actual spherical objects. The results suggest that the frontal surface of mid-air images is generally perceived on the image plane or behind it. However, when depth is recognized, it appears slightly less pronounced compared to actual objects.

## **CCS** Concepts

• Human-centered computing  $\rightarrow$  Visualization.

### Keywords

mid-air image, perception, depth, thickness

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#### 1 Introduction

We focused on the fact that many users reported perceiving midair images as three-dimensional when presented on a 2D light source display. Furthermore, we are interested in how often users move their fingers past a mid-air image when touching it. This phenomenon suggests that while subjects experience a sense of three-dimensionality in relation to the mid-air image, they struggle to accurately localize its precise spatial position.

In this study, we quantified the perceived depth and position of two-dimensional mid-air images, as reported by participants, using a pointing task paradigm. Specifically, the user is instructed to point to two locations: the nearest front and zenith of the sphere, which is displayed as a mid-air image, as shown in Figure 1. First, to determine the perceived position of the nearest front, participants moved their index fingers. Subsequently, they pointed to the zenith. It clarifies the sense of depth in a spherical mid-air image by measuring the difference in the distance from the nearest front to the zenith. Additionally, the participants performed the same pointing movements as the real object. The two were compared to

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Figure 1: Front and Zenith pointing positions

investigate the relationship between the three-dimensionality of the mid-air image and the real object.

## 2 Related work

A mid-air image is a real image formed in air through the reflection and refraction of light emanating from a source and is manipulated by specific optical elements. The micro-mirror array plate (MMAP)[Maekawa et al. 2006] and aerial imaging by retroreflection (AIRR)[Yamamoto et al. 2014] are well-known optical systems for mid-air imaging. These systems facilitate the direct observation of mid-air images without the need for specialized viewing apparatus.

MARIO[Kim et al. 2014] is an interaction system that uses midair images. In this system, a shadow is displayed under a mid-air image to make it easy for the user to determine the depth of the mid-air image. However, it remains unclear how users perceive the position of mid-air images without these cues.

In a study of perceptual changes in mid-air images, Yano et al. examined the effect of shadow length on the perceived thickness of mid-air images [Yano and Koizumi 2023]. They found that longer shadows increased perceived thickness, whereas shorter shadows decreased it. However, this study did not quantitatively measure the perceived thickness without shadows.

#### 3 Method

White polystyrene with a diameter of 10 cm was used to present a real sphere. We chose Styrofoam to minimize the impact on the perception of three-dimensionality due to surface texture using a material where gloss and shadows are less pronounced. However, to show a spherical mid-air image, a monochromatic white sphere was displayed to make it look similar to the real object. The mid-air image was adjusted to a diameter of 10 cm when displayed on a screen. A position of the fingers, Trio optical motion capture system OptiTrack V120: Trio was used to measure the finger position. A spherical mid-air image is presented using MMAP as shown in Figure 2. The imaging plane was positioned 47 cm away from the center of the MMAP. During the experiment, the participants' head SA Posters '24, December 03-06, 2024, Tokyo, Japan



Figure 2: Device for presenting sphere of mid-air image and state of pointing action

positions were stabilized using a chin rest to ensure that they faced forward. The eye position was aligned with the center of the midair image, which was situated 30 cm in front of the mid-air image plane.

Pointing was performed under two conditions: a real sphere and a mid-air image sphere, and the positions of the fingertips were measured. First, a real sphere was presented in front of the participants and observed from the front. Subsequently, the sphere was removed, and the participants were asked to point to the position nearest to the sphere. The same procedure was used to point to the zenith. Real objects were removed during pointing to eliminate tactile cues. During mid-air image presentation, the experiment was conducted using the displayed image. The participants were 10 males aged 21-26 years with normal vision.

### 4 Result

To compare the differences between the two conditions, the mean pointing position over the five trials for each participant was plotted, as shown in Figure 3. The horizontal axis indicates the position of the finger in the depth direction, with the original front position of the sphere set to 0 cm. The larger the value on the horizontal axis, the farther back the finger is pointed compared to the original front position. Figure 3 shows that pointing to the nearest front of a real object tends to bring the finger a range of approximately 3 cm forward and backward from the original front position of the object. However, when pointing to the same mid-air image, the finger tends to be within about 4 cm behind the image plane. This suggests that the front of the sphere in the mid-air image was perceived on or behind the mid-air image plane, rather than at the front side of the image plane.

Furthermore, Figure 4 shows the results of the calculation of the perceived depth sense, that is, the difference in depth between the zenith and nearest front, for each participant in the two conditions. The red dotted line shows the distance of 5 cm from the nearest front to the zenith of the 10 cm sphere. A comparison of the two conditions showed that more subjects in the mid-air image condition perceived a depth of below 5 cm for the same-sized sphere than in the real condition.



Figure 3: Pointing position of the front and zenith of a real and mid-air image sphere



Figure 4: Difference in perception of depth sensation between real and mid-air image spheres. The perceived depth sense refers to the difference in depth between the zenith and the nearest front

## 5 Conclusion

In this study, we clarify a position of a two-dimensional mid-air image perceived by a user and the sense of depth by measuring it through pointing. Experimental results demonstrated two facts. First, the nearest front of the mid-air image was perceived as being on or behind the imaging plane. Second, although the depth of the mid-air image is perceived, it is slightly reduced compared to that of the actual object. In the future, we aim to investigate how the perceived depth of mid-air images changes with the addition of textures and animations as well as with variations in shading and shape.

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