Can Shadows Create a Sense of Depth to Mid-air Image?

Yutaro Yano
y.yano@media.lab.uec.ac.jp
The University of Electro-Communications
Chofu, Tokyo, Japan

Ayami Hoshi
a.hoshi@media.lab.uec.ac.jp
The University of Electro-Communications
Chofu, Tokyo, Japan

Naoya Koizumi
koizumi.naoya@uec.ac.jp
The University of Electro-Communications
Chofu, Tokyo, Japan

ABSTRACT

Shadows are an important factor in the perception of object position and shape. In this study, we investigated the effect of shadows on the perception of the shape of a mid-air image by projecting shadows of different shapes onto a mid-air image that is displayed in real space. Specifically, participants viewed one oval cylinder with a shadow and one oval cylinder without a shadow individually and were forced to choose which had the greater thickness in the depth direction. As a result, we found that different shadow shapes changed the perception of the thickness of the mid-air image.

CCS CONCEPTS

• **Human-centered computing → Visualization**.

KEYWORDS

shadow, mid-air image, thickness perception

ACM Reference Format:

Yutaro Yano, Ayami Hoshi, and Naoya Koizumi. 2021. Can Shadows Create a Sense of Depth to Mid-air Image?. In *Proceedings of SIGGRAPH Asia 2021 (SA '21 Posters).* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/1122445.1122456

1 INTRODUCTION

Shadows impact how we perceive the position and shape of objects. Many studies have studied the effects of shadows on perception. Several studies have shown that shadows have an effect on the perception of the position, shape and reality of real objects[Kawabe 2019] [Kim et al. 2014].

Based on these findings, we contribute a hypothesis toward solving the problem of "difficulty in perceiving thickness"—which is a weakness of mid-air images—by projecting shadows on mid-air images in real space. In this study, we investigate the effect of projecting different shadow shapes onto a mid-air image on the perception of the mid-air image's shape.

2 METHOD

2.1 System Design

In this system, a projector projects a shadow onto the 3D mid-air image, formed by the light from the 3D display. Figure 1 shows the optical design of the experimental system. The system consists of a 3D display, micro-mirror array plates (MMAPs), and a projector. The light emitted from the display is retroreflected through the MMAPs to form a mid-air image. The MMAPs is placed at 45° and the 3D display at 15°.

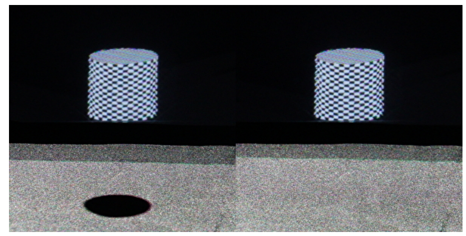

Figure 1: Left: Mid-air image with shadow. Right: Mid-air image without shadow.

2.2 Procedure

This experiment was conducted based on the constant method. The standard stimulus is a cylinder with a horizontal diameter of 4 cm, a depth of 4 cm, and a height of 4 cm, combined with a shadow with a horizontal diameter of 4 cm and a depth of r cm, and the comparison stimulus is an oval cylinder with a horizontal diameter of 4 cm, a depth of r′ cm, and a height of 4 cm. The participants viewed the standard stimulus and the comparison stimulus individually and were forced to choose which had the greater thickness in the depth direction. The values of r and r′ were set as follows. Note that the position of the center of the oval cylinder was the same for all values of r′.

r = {2.0, 3.0, 4.0, 5.0, 6.0} [cm]

r′ = {2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5} [cm]

This was one trial, and a total of 35 trials were conducted in which each of the five standard stimuli was multiplied by seven comparison stimuli. Both the order of presentation of these trials and the order of presentation of the standard and comparison stimuli in each trial were random. The experiment time per person was about 10 minutes. Eleven participants (21 – 27 years old) participated in the experiment, and all tested positive for proper stereopsis function in the stereo test prior to participating.

3 RESULTS

Figure 2 shows the percentage of respondents who answered that "the mid-air image without shadow was thicker in the depth direction than the mid-air image with shadow" for each standard stimulus trial and the results of S-curve fitting using the cumulative normal distribution function. We defined the point of subjective

SA '21 Posters, December 14–17, 2021, Tokyo, Japan

ACM ISBN 978-1-4503-XXXX-X/18/06.
https://doi.org/10.1145/1122445.1122456

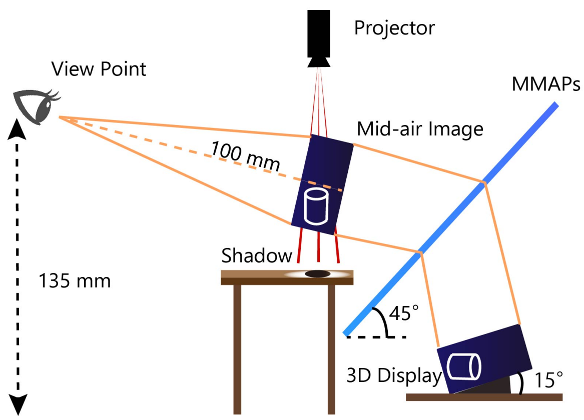

Figure 2: System Design. When the light incident on the MMAPs from the light source is reflected, the mid-air image is formed as a real image at the plane symmetry position. A shadow is projected directly below the formed mid-air image.

equality (PSE) as the thickness of the mid-air image without shadow when the percentage of participants who answered "the mid-air image without shadow is thicker" was 50% in the experiment at each shadow length. This means that at the PSE, the mid-air image with a depth of 4 cm projected a shadow of r cm and the mid-air image with out shadow were evaluated to be equal in thickness. The results of PSE for each shadow length r are summarized in table 1. This result shows that the perceived thickness of the mid-air image in the depth direction changes depending on the length of the shadow in the depth direction.

4 DISCUSSION

In the shadow length range of 4.0 cm to 6.0 cm, the perceived thickness of the mid-air image did not change as much as in other ranges. From this result, we concluded that when the length of the shadow exceeds a certain length, the correspondence between the shadow and the object is lost. In addition, participants felt that "this shadow is not cast by this object," and the effect of the shadow on shape perception was weakened.

This experiment focused on the effect of the shadow shape on the perception of the thickness of the mid-air image, but the direction setting and shadow position also needs to be considered. The direction and position of the shadow projected on the mid-air image in this experiment may not match the direction and position of the shadow of the object in the real world due to differences in the direction and position of the virtual light source. By taking these factors into account when creating shadows, projected shadows may change perception of the mid-air image's shape.

5 CONCLUSION AND FUTURE WORK

In this study, we found that the perception of the mid-air image's thickness in the depth direction changes by projecting shadows of different shapes onto the mid-air image. From a result of calculating the value of PSE, we also identified that the apparent thickness of the mid-air image becomes difficult to change when the length of the shadow exceeds a certain length. In the future, to more closely examine how the shadows add a sense of depth to the mid-air image, we will conduct experiments with additional conditions of the direction and position of the shadows and object shape conditions, other than those used in this experiment. We are also planning to create a 3D mid-air image that exceed the depth range that 3D displays can represent by using the knowledge obtained from this study.

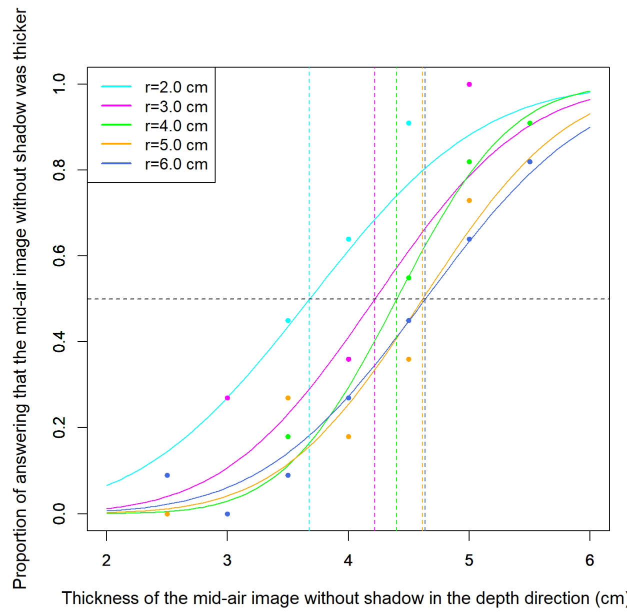

Figure 3: Results of plotting the cumulative normal distribution function. Each point represents the proportion of answering "the mid-air image without shadow is thicker than the mid-air image with shadow" when using the data of the participants in the experiment.

Table 1: Value of PSE for each shadow length

Shadow Length (cm)	PSE (cm)
2.0	3.67
3.0	4.21
4.0	4.40
5.0	4.61
6.0	4.64

ACKNOWLEDGMENTS

This work was supported by the Hoso Bunka Foundation.

REFERENCES

Takahiro Kawabe. 2019. Shadow-Based Illusion of Depth and Transparency in Printed Images. *ACM Trans. Appl. Percept.* 16, 2, Article 10 (Aug. 2019), 12 pages. https://doi.org/10.1145/3342350

Hanyuool Kim, Issei Takahashi, Hiroki Yamamoto, Satoshi Maekawa, and Takeshi Naemura. 2014. Mario: Mid-air augmented reality interaction with objects. *Entertainment Computing* 5, 4 (2014), 233–241.