Micro-mirror array-plates simulation using ray tracing for mid-air imaging

Author name 1*
Organization or School 1

Author name 2†
Organization or School 1
Organization or School 2

ABSTRACT

We present a simulation of micro-mirror array plates (MMAPs) using ray tracing for displaying a mid-air image. MMAPs form a mid-air image in the plane-symmetrical position with respect to MMAPs. However, MMAPs have two limitations: generation of undesired images and limited the visible range. Since these limitations change depending on the structure of a mid-air imaging system or observing position, it is difficult for non-optical designers to use such as system. To solve this problem, we provide a ray tracing based simulation for MMAPs. We investigated the optimum parameters to form a mid-air image using ray tracing. We then compared a simulated computer graphics image and an actual photo to confirm whether characteristics of MMAPs can be simulated.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Display and Imagers;

1 INTRODUCTION

Visual-information-presenting methods are one of the most impotant topics for MR and AR. Mid-air imaging is one of them that can display computer graphics (CG) in real space. This enables users to easily interact with a CG image in the air without holding or wearing devices or using wall or fog like a projection mapping.

Micro-mirror array plates (MMAPs) can display mid-air image in real space, but they have two limitations such as the formation of undesired images and limited visible range. MMAPs form a mid-air image in the plane symmetric position from the light source. However, two types of undesired images are generated, and they tend to interfere with an observer's viewing of a mid-air image. The visible range of mid-air image is limited and changes depending on the relative positions of the light source and optical elements. Therefore, designing a mid-air imaging system using MMAPs is difficult for non-optical designers.

We present a simulation of MMAPs by generating the appearance of mid-air image in CG. We investigated optimum rendering settings to clearly render the appearance of a mid-air image using ray tracing. Furthermore, we experimentally confirmed characteristics of MMAPs, i.e., plane symmetry, undesired images, and limited visible range can be simulated with our simulation.

2 RELATED WORKS

There are several mid-air imaging optical elements, such as MMAPs, aerial imaging by retro reflection [1], the dihedral corner reflector array [2]. Mid-air imaging enables to interact with CG characters in the air without wearing or handling special equipments.

Otao et al. [3] used a method of describing the path of light rays to simulate MMAPs. This method can simulate the imaging position and the traveling direction of the light rays. However, this method cannot simulate the appearance of a mid-air image.

*email:
†email:

Figure 1: (Left) Mid-air image formed in real space. (Right) Mid-air image rendered with our simulation.

Ray tracing can be used as an optical simulation method [4]. Ray tracing is a method of drawing an object by tracing the light rays from the viewpoint of camera in CG space. Since this method can generate a photorealistic CG, it has been used in industrial design when a user wants to design the details of products [5]. We argue that ray tracing is useful to design a combination of mid-air image and interiors or architecture.

3 MODELING AND RENDERING

To simulate the MMAPs, we modeled them and rendered mid-air images using ray tracing. We used Blender 2.80[1] for modeling and Cycles[2] for rendering built in Blender as a rendering engine. All rendering was conducted on a desktop computer with Intel Core i9-9980XE CPU clocked 3.0 GHz and GeForce RTX 2080 Ti GPU.

3.1 Modeling

We modeled MMAPs to render mid-air image. The MMAPs we used when modeling are the optical imaging device TRG-0002 manufactured by ASUKANET. These MMAPs have 2760 micro-mirrors which are made of soda lime glass with a thickness of 0.5 mm and height of 1.5 mm, both sides of the soda lime glass are subjected to mirror deposition. Therefore, the spacing between each mirror is 0.5 mm. However, if we model a glass that is used in MMAPs, not only the reflection on the mirror but also the refraction and the reflection on the glass are need to calculated while rendering. We considered that the reflection and the refraction of the glass can be ignored because it is very thin and highly transparent. Therefore, we only modeled mirrors to decrease the calculation in rendering. A modeled mirrors have a completely smooth surface and 100% reflectivity. Using the above settings, we modeled MMAPs with assuming a unit distance in Blender is 1 cm in real.

3.2 Rendering

We investigated appropriate rendering parameters for generating a mid-air image through simulation. We first describe the general settings for rendering, such as integrator, the number of sampling, the resolution of image, and settings of camera. We specified path tracing as integrator, and used GPU to compute. The number of sampling for each pixels was 1024, rendering resolution was 1080×720 pixels, and focal length of the camera was 35mm. With the above

[1]https://www.blender.org/
[2]https://www.cycles-renderer.org/

settings, partly missing mid-air image was rendered. To render bright and accurate mid-air image, we first adjusted `Glossy` value that is the maximum number of tracing rays of the gloss reflections. `Glossy` is set to 4 as default in Blender, then partly missing mid-air image was rendered. If `Glossy` is set to 5 or more, not lacked mid-air image is rendered, and we set it to 40. In this time, rendered mid-air image seems to be dark. Therefore, we adjusted `Indirect Light` value that is the maximum intensity of indirect light. It is set to 10 as default, but we set the light-emission intensity of the light source to 100. So, we also set `Indirect Light` to 100, and a bright mid-air image was rendered. The images without adjustment of `Glossy` and `Indirect Light` were rendered in about 21 seconds per image, and the images with adjustment them were rendered in about 26 seconds per image.

4 Evaluation

We confirmed that three characteristics of MMAPs are simulated by experiments. First, we verify whether the plane symmetry is simulated in our simulation to determine the imaging position of a mid-air image. We used stereo algorithm to determine the imaging position and confirmed that mid-air image in our simulation was formed at plane symmetry position with respect to MMAPs.

Second, we compared the behavior of undesired images in real space and through simulation. Undesired images appeared next to mid-air image and its shape was as if the mid-air image was sheared in a certain direction, as shown in Fig. 2. The position change and shear between the mid-air and undesired images were explained using an affine transformation matrix. Therefore, we calculated the similarity between two matrices between the mid-air image and undesired images in the photo and rendered image to evaluate undesired image. Fig. 3 shows the experimental results. The measured value was set to 0 for the part when the mid-air image or undesired images were missing. The result indicated that two affine matrices were almost equal. Therefore, shear and position change between mid-air and undesired images can be simulated.

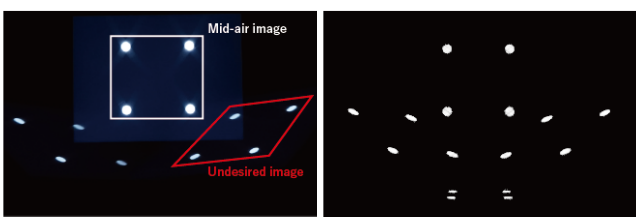

Figure 2: (Left) Mid-air image photographed in real space, (Right) Mid-air image rendered by our simulation.

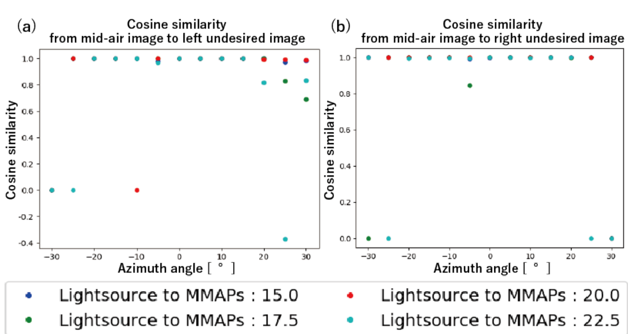

Figure 3: similarity of affine transformation matrices

Third, we compared the visible range of the mid-air image in real space and simulation. The mid-air image was clipped or invisible outside the visible range. The visible range changes depending on relative positions of the optical-system equipment such as distance between light source and MMAPs. In this experiment, we evaluated whether the visible range corresponding to the distance between the light source and MMAPs could be simulated by comparing the area of the mid-air image depending on the observing angle. Fig. 4 shows the experimental results. Comparison between real space and simulation shows that the range for keeping values close to 1 was similar. This result indicated the visible range of the mid-air image can be simulated. This result also indicated the visible range was widest when the distance between light source and MMAPs was 35cm. Therefore, our simulation can help to design mid-air imaging system to take into account the visible range.

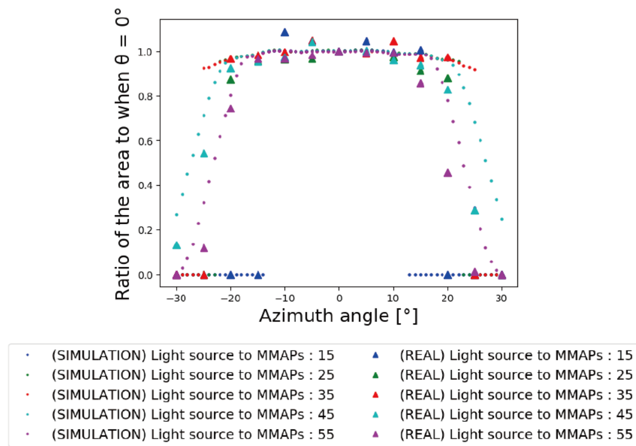

Figure 4: Results of measuring ratio of the area of mid-air image to when $\theta = 0°$.

5 Conclusion

In this paper, we presented MMAPs simulation using ray tracing to design mid-air imaging optical systems in computer. We investigated appropriate rendering parameters to draw mid-air image with ray tracing. We compared the simulated CG and actual photo of mid-air image to confirm whether three characteristics of MMAPs could be simulated to simply model MMAPs.

Acknowledgments

This research was supported by xxxx.

References

[1] H. Yamamoto and S. Suyama. 64.3l: Late-news paper: Aerial imaging by retro-reflection (airr). *SID Symposium Digest of Technical Papers*, Vol. 44, No. 1, pp. 895–897, 2013. doi: 10.1002/j.2168-0159.2013.tb06364.x

[2] D. Miyazaki, S. Onoda, Y. Maeda, and T. Mukai. Blurring correction for aerial image formed by dihedral corner reflector array. In *2015 11th Conference on Lasers and Electro-Optics Pacific Rim (CLEO-PR)*, Vol. 1, pp. 1–2, Aug 2015. doi: 10.1109/CLEOPR.2015.7375811

[3] K. Otao, Y. Itoh, K. Takazawa, H. Osone, and Y. Ochiai. Air mounted eyepiece: Optical see-through hmd design with aerial optical functions. In *Proceedings of the 9th Augmented Human International Conference*, AH '18, pp. 1:1–1:7, New York, NY, USA, 2018. ACM. doi: 10.1145/3174910.3174911

[4] T. Whitted. An improved illumination model for shaded display. In *ACM SIGGRAPH 2005 Courses*, SIGGRAPH '05, New York, NY, USA, 2005. ACM. doi: 10.1145/1198555.1198743

[5] I. Wald, A. Dietrich, C. Benthin, A. Efremov, T. Dahmen, J. Gunther, V. Havran, H. Seidel, and P. Slusallek. Applying ray tracing for virtual reality and industrial design. In *2006 IEEE Symposium on Interactive Ray Tracing*, pp. 177–185, Sep. 2006. doi: 10.1109/RT.2006.280229