Sunny Day Display: Mid-air Image Formed by Solar Light

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ABSTRACT

We propose a mid-air imaging technique that is visible under sunlight and that passively reacts to light conditions in a bright space. Optical imaging is used to form a mid-air image through the reflection and refraction of a light source. It seamlessly connects a virtual world and the real world by superimposing visual images onto the real world. Previous research introduced light emitting displays as a light source. However, attenuation of the brightness under a strong light environment presents a problem. We designed a mid-air imaging optical system that captures ambient light using a transparent LCD (liquid crystal display) and a diffuser. We built a prototype to confirm our design principles in sunlight and evaluated several diffusers.

Our contribution is three-fold. First, we confirmed the principle of the mid-air imaging optical system in sunlight. Second, we chose an appropriate diffuser in an evaluation. Third, we proposed a practical design which can remove disturbance light for outdoor use.

Author Keywords

Mid-air imaging, Sunlight, Outdoor, Mixed reality

ACM Classification Keywords

I.4.0 Image processing and computer vision: General image displays

INTRODUCTION

Interactive surfaces and spaces sense human behavior and present information in accordance with it. In this research, we propose a new technique of mid-air imaging and make a contribution towards the fields of spatial display.

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Figure 1. Sunny Day Display. Mid-air image is visible and floats above hand using light from sun.

Mid-air imaging is a promising way to generate glass-free mixed reality interaction. Several optical designs have been proposed that show mid-air images in three-dimensional space. There have been several studies on mid-air imaging and interaction systems [1]. These systems utilize optical devices to form mid-air images with normal liquid crystal displays (LCD) as a light source. However, these techniques suffer from a lack of brightness because of attenuation caused by the reflection or diffusion of light, so they require the use of high brightness displays. However, these displays are heavy and consume a lot of power; therefore, we need a high brightness display without high power consumption.

In this paper, we present the Sunny Day Display: a novel mid-air imaging technique for illuminated spaces such as those under sunlight, which incorporates both solar light reflection and a suitable diffuser into traditional mid-air imaging.

The Sunny Day Display aims to increase the brightness of an image to overcome ambient light and to display a mid-air image in real-world environments such as a park. To achieve this functionality, as shown in Figure 1, the system is equipped with 1) an aerial imaging plate (AIP) that utilizes a two-layered micro-mirror array, 2) a transparent LCD, 3) a diffuser, 4) a polarizer and 5) light shields.

In summary, the main contributions of this paper are:

- We proposed a technique to take ambient light such as solar light to form a midair image to reduce electrical power consumption of a light source.
- We showed that selection of the diffuser plate is important because forming a midair image by simply changing the light source display to a transparent LCD is impossible.
- An optical system that cuts outside light and clearly shows the mid-air image has been proposed so that it can be used under noisy ambient light.

RELATED WORK

Mid-air Imaging

There are several techniques for forming mid-air images such as reflecting a light source to form an image in the air, using plasma emission by a laser, and using a fog display. The laser technique can realize light emission in three dimensions [2, 3]. It is also being developed by Burton Inc. to express outdoor high-intensity mid-air images [4]. Although this can realize high luminance light emission, it is basically premised on use in spaces inaccessible to human hands.

Fog display is a technique for controlling the diffusion of light through projection on fog [5]. Since fog has less influence on the human body, various interactions can be realized [6]. Regarding the display, the degree of freedom is high; for example, in Tokuda et al.'s study, increasing the degree of freedom of shape by controlling the generation of fog is possible [7]. On the other hand, using it outdoors is difficult because fog is received by wind.

FLOATS V [8] and FuwaVision [9] are available as techniques using Fresnel lenses. They can present three-dimensional images by presenting different images to the left and right eyes. However, a problem exists in which the position of the viewpoint is limited in the mid-air image of the Fresnel lens. Therefore, using it in a situation in which there are multiple people viewing is difficult. For example, HaptoMirage [10] can project 3D contents in mid-air and enable as many as three participants to observe the same contents with a 150-degree wide-angle view by using the Kinect sensor, but its feedback delay is a shortcoming when it comes to a user's first motion. On the other hand, the retroreflective optical system is easier to handle than the conventional nonlinear optical system including the Fresnel lens in that there is no restriction on the viewpoint position. There are several retroreflective optical systems such as the aerial imaging plate (AIP) [11], DCRA [12], AIRR [13], and RMA [14]. In this research, we use the AIP because it is a commercially available optical device and is easy to install. Figure 2 illustrates the optical properties of an AIP. Incident light, reflected two times in a mirror, converges at a position that is plane-symmetric to the AIP. Since it does not have a fixed focal length, the imaging position can easily be moved by changing the distance between the light source and the AIP without changing the size of the resulting images [11]. It is not suitable for the AIP to use a heavy display such as a high brightness LCD because the display needs a powerful actuator to move it. In other words, with a conventional optical design using an AIP, using it in a bright place is difficult. In order to overcome this difficulty, we incorporate the concept of a passive light display.

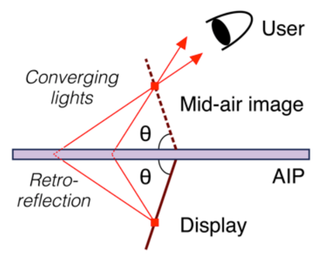

Figure 2. Optical properties of aerial imaging plate (AIP).

Passive Light Display

Passive light display is a display technique with ambient light. Printing reflects the ambient light, so its visibility depends on the brightness of the environment. Similar to this phenomenon, there are several passive light displays. For example, Fuchs et al. presented a multi-dimensional display that passively reacts to the light of the environment behind it without any sensors [15]. Yue et al. presented a technique of creative and enjoyable pixel art by rearranging a set of sticks made from acrylate resin, and by positioning this set appropriately between a parallel light source (e.g., sun-light or a projector) and a viewing surface (screen), one can observe the resulting pixel art on the screen [16]. In this study, we use a passive light display for a mid-air imaging technique. A passive midair image [17] was already proposed, but it is not suitable for sunlight because the position of the display is below the AIP, making capturing sunlight difficult. The goal of this research is to achieve a mid-air image optical system that takes light from the top to efficiently capture sunlight.

APPROACH

Design

We propose another way to achieve a bright display that takes in sunlight because the sun is the brightest light source. The simplest way is to use a reflective LCD. However, when a reflective LCD is placed in the system, it reflects the light coming from above and directs it upward. In this case, the shadow of a person can disturb it, so it is difficult to take in ambient light. The reflective LCD also reflects light even if it displays black and forms a black mid-air image. Therefore, it is better to use a light shutter to form a clear image. In this study, we control the transmission of light by using a transparent LCD as a base for displaying content. A transparent LCD is an LCD without a backlight. We designed the optical design of the structure to form a mid-air image using the AIP with ambient light.

Figure 2 shows our proposed principle. The light from the sun diffuses and goes through the transparent LCD to form a virtual display. Because the light from the sun is directional light, it is necessary to diffuse it. Transparent LCD controls the graphics of mid-air image. Then the light goes into the AIP and is reflected to form a mid-air image. In order to prevent undesirable light, we shielded the AIP other than in the imaging direction of the mid-air image with light shielding material.

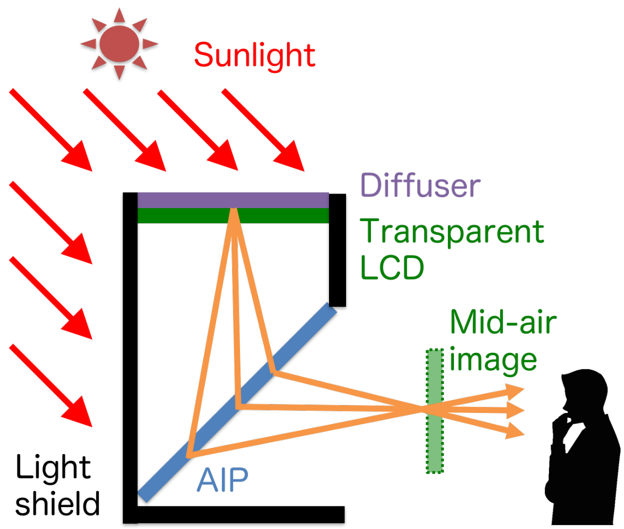

Figure 3. Principle of Sunny Day Display.

Prototype

To confirm the validity of our optical design, we prototyped an experimental model. We use a 488 mm square AIP (Asukanet), transparent LCD (VL190EG02-TRP, transparency 8%), and several diffusers.

Figure 4 shows the structure of the prototype. During the experiment, we surrounded the equipment with light absorbing material to prevent extra light intrusion.

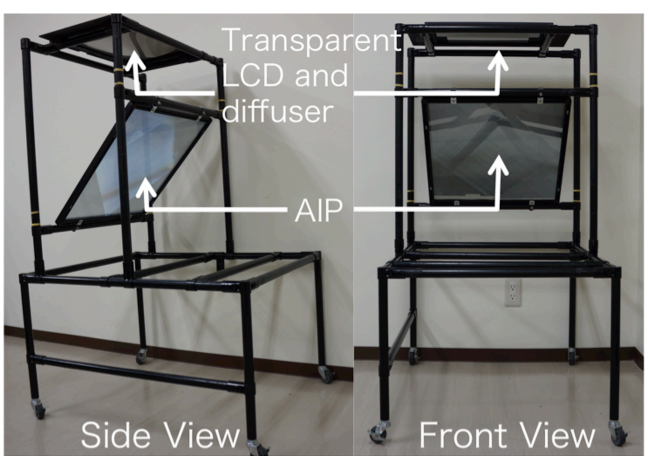

Figure 4. Structure of Sunny Day Display.

SELECTION OF DIFFUSER

The brightness of our proposed design is determined by the specifications of the transparent LCD and diffuser. The light transmittance of a typical transparent LCD is about 8%. In contrast, the diffusion plate caused a large difference in viewing angle and haze. Therefore, we evaluated diffusers to find one that is suitable for our proposed design.

Setup and Materials

To confirm the validity of our optical design, we prototyped an experimental model with the AIP, transparent LCD, and several diffusers and evaluated the luminance. It was measured at several angles: at the front and at angles of 5°, 10°, 15°, and 20°. At the same time, we compared the luminance of several diffusion plates: ten light shaping diffusers (LSD0.5, 1, 2, 5, 10, 20, 30, 40, 60, 80. Luminit), a sheet of Japanese paper, and three types of rear-projection film (rear transparent, rear black, and rear semi-transparent. Theaterhouse). We also used a light source (YN600L II, Yongnuo) instead of sunlight. Figure 5 shows the experiment setup.

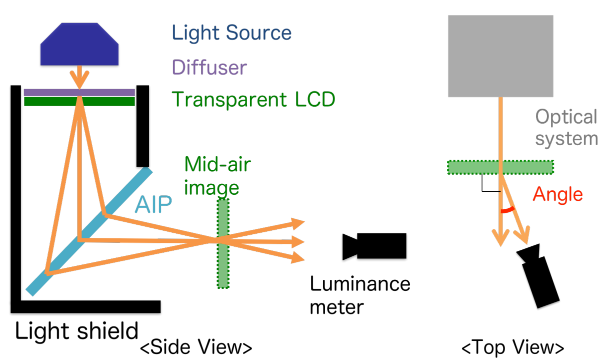

Figure 5. Setup of experiment. Light direction is fixed vertically downward.

Result

Figure 6 shows the results of the experiment. The LSD0.5 obtained the highest brightness in front, at 5°, and at 10°. However, its brightness suddenly decreased at 15°. According to [1], a mid-air image can be seen within 35.1°–68.7° in the horizontal direction and 21.6°–59.3° in the vertical direction. Therefore, the viewing angle of LSD0.5 is too narrow. In contrast, LSD2 works well at 20°. For these reasons, LSD2, which was high in brightness throughout the whole range of angles, was used.

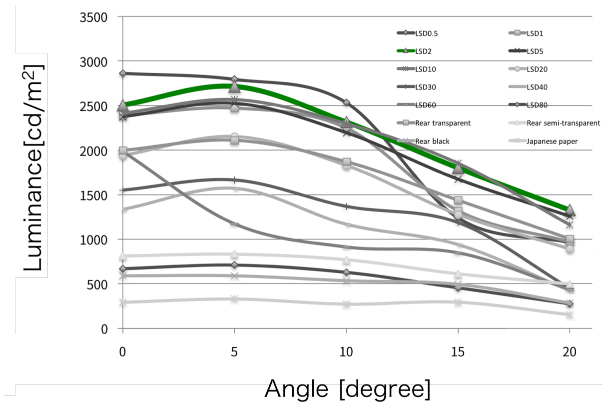

Figure 6. Setup of experiment. Light direction is fixed vertically downward.

EVALUATION

We evaluated the basic performance of this optical system as a display. First, since the brightness depends on the environmental illuminance, the brightness of the mid-air image was measured by adjusting the brightness of the illumination light. We also evaluated the contrast and confirmed that a clear image can be presented. These experiments were carried out in a dark room. In addition, we measured the luminance of the mid-air image using sunlight as a light source and confirmed that a visible mid-air image was formed. In all experiments, we blocked the periphery of the AIP by blackout to prevent the influence of external light.

Brightness

Using the selected diffuser, we investigated the relationship between the intensity of the light source and the brightness of the mid-air image. This evaluation was conducted in the same environment as the above experiment. We controlled the intensity of the shooting light, which was mounted to the upper part of the prototype.

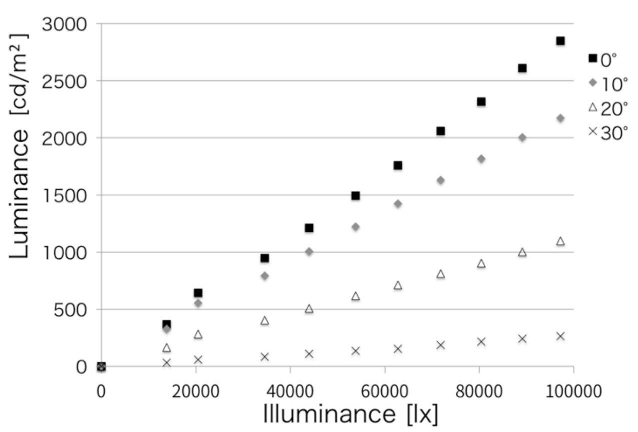

Figure 7. Relation between illuminance and luminance for each view angle.

Figure 7 shows the result of this experiment. The vertical line is the luminance of the mid-air image, and the horizontal line is the illuminance of the light source at the upper surface of the transparent LCD. According to the graph, the relationship between the illuminance and the luminance is proportional. The highest brightness is at 0°. The brightness decreases as the measurement angle increases.

Contrast

An evaluation was carried out with respect to contrast. The experiment was carried out in the same environment as described above. The brightness of the illumination was constant, and the white level was varied from 0 to 255. The brightness of the mid-air image was then measured. The brightness of the lighting in this experiment was 90,600 lx.

Figure 8 shows the results of this experiment. The vertical line is the luminance of the mid-air image, and the horizontal line is the white level of the transparent LCD. It is not a proportional relationship; however, the results show that this optical design can control the contrast of a mid-air image similar to the control of a normal display.

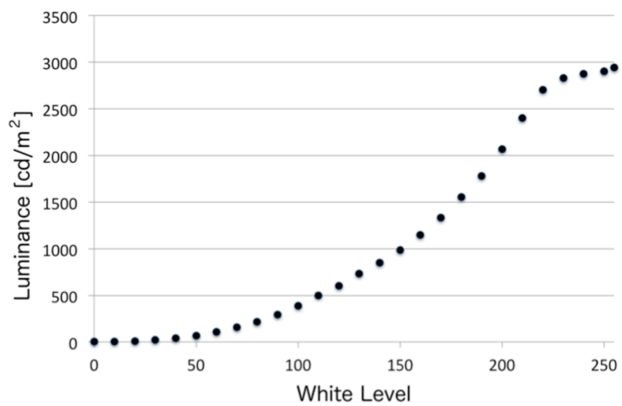

Figure 8. Luminance of a mid-air image based on white level of a transparent LCD.

Outdoor Usage with Sunlight

We measured the luminance of the mid-air image in an outdoor environment. We put our prototype outside on September 1, 2016, in Tokyo. The weather conditions were fine. The experiment setup was the same, but we put a black cloth on the ground to prevent the reflection of sunlight. The maximum luminance was 355 cd/m^2 when the illuminance was 12,280 lx, which is bright enough to see the image outdoors.

DISCUSSION

Disturbance Light from viewing side

We applied a practical design by applying the proposed principle. When applying the principle as it is, the influence of ambient light due to diffuse reflection of sunlight is a problem. It was wrapped with light shielding, but covering all sides is impossible because it needs a way to emit light. Diffuse reflection light from outside the system is reflected on the glass of the AIP and glows brightly. Therefore, it is necessary to reduce disturbance light entering the AIP as much as possible. Figure 9 shows our practical design. Our idea is to peel off one transparent polarizer and attach it to the front of the AIP. Even in this design, since there is no change until the mid-air image is formed, the brightness and resolution of the mid-air image do not decay. However, since the ambient light is cut by the polarizing plate, the influence of disturbance can be largely eliminated. This makes it possible to display midair images robustly even in outdoor environments.

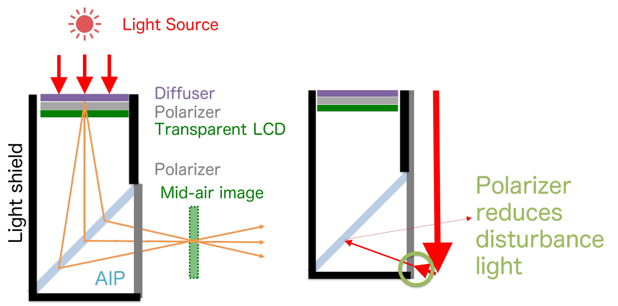

Figure 9. (a) Design of a midair image optical system with measures against disturbance light. (b) How to remove disturbance light by polarizer.

Application
This technique is expected to be applied as outdoor digital signage. For example, when the user is facing the system, the mid-air image is moved to the front of the audience and produces images like in science fiction movies. Existing digital signage will evolve from something that human beings look at to something that appears closer to humans. We demonstrated a system in which the mid-air image moves around in the depth direction, up and down, and left and right at the open campus of our university. Figure 10 shows the motion of the mid-air image in the depth direction. According to our observations, many viewers stretched their hands naturally and confirmed that there was nothing there when they found the mid-air image. After that, when moving the mid-air image closer to the viewers, they were surprised by the movement. In the future, we would like to confirm the effect of this mid-air image movement on people.

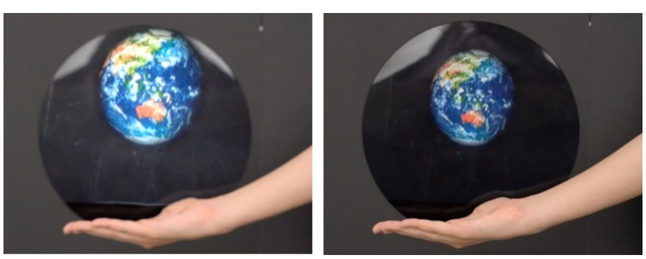

Figure 10. Depth Motion. Size of mid-air image is same, but distance between user and mid-air image is different, so size of earth image is seen as different.

Advantage
The advantages of this system are its low power consumption and ease of content creation. For power, the transparent LCD needs only 25 W. In contrast, a normal LCD of the same size needs about 50 W to power the backlight. Additionally, the brightness of the mid-air image based on a normal LCD is darker than that of our system.

Regarding content creation, designers can use the images just as they would in a normal display; therefore, they do not need anything new for mid-air image creation.

We compare this technique with the others using a high brightness display. In this technique, the mass of the light source is lightweight since there is no backlight. Therefore, the merit of our proposal is that the cost for moving representation of the mid-air image in the depth direction is low because the movement of the light source can be realized more easily.

Limitation
The limitation of our proposal is that we need a light source. In other words, it cannot be used in a dark space. For this purpose, it is possible to use a conventional general display as a light source. In the future, we will develop a control technique of auxiliary light in accordance with the illuminance of the surrounding environment.

There is also a resolution limitation. This is because the resolution of the image drops in the process of reflection by the micro-mirror array. According to [18], it is said to be readable for 5 × 7 mm characters. The resolution is considered to be different depending on the distance between the light source and the AIP, so a detailed design is required in the future.

There is also a limitation in which it is impossible to see the background of the AIP because it is necessary to shield light.

Issues
There are some issues regarding outdoor use. One big problem is overheating. To prevent the reflection of undesired light, the system must be covered by a shading material. However, this material absorbs the energy from the sun and overheats. Therefore, the system needs a heat protection mechanism, e.g., a water cooling system or heat reflection film.

CONCLUSION
The aim of our research was to realize an MR environment in an outdoor environment without any special wearable devices. We focused on mid-air images to solve this problem; however, a large amount of power is needed to form a mid-air image because of the need for a high-luminance display. In contrast, our idea is to use sunlight instead of a power-consuming backlight.

Our research novelty is an optical design for forming mid-air images by using ambient light such as sunlight. Our research contributions are the confirmation of the principles of a mid-air imaging technique using sunlight, the selection of the LSD2 as an appropriate diffusion plate as confirmed in a prototype evaluation, and a practical design for reducing disturbance light by replacing the polarizer.

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