SMALL CYLINDRICAL DISPLAY FOR ANTHROPOMORPHIC AGENTS

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ABSTRACT

This paper describes a small cylindrical display for an anthropomorphic agent that communicates with users in a three-dimentional (3D) environment. Conventional displays for anthropomorphic agents are designed for a single user or a fixed viewing direction. We suggest a new small cylindrical display that is visible from the outside in any direction. Image data for the projector is calculated by the image-warping method. Light emitted from the image projector is reflected by a spherical mirror and projected on the inside of the rear of the cylindrical screen. This cylindrical display enables 3D agent actions, such as head turning. We evaluated our display by measuring pixel brightness in different situations. We demonstrate an application of anthropomorphic agents and a telecommunications system using omnidirectional images.

1. INTRODUCTION

A person can freely communucate with others in any direction by turning the head, looking at another person's face, and talking. It is desirable that anthropomorphic agents are also able to communicate with many users in any direction. However, most displays for anthropomorphic agents [1] are fixed planar types, and the agents therefore have difficulty communicating with anyone other than the person in front of them. Recently, a cylindrical three-dimentional (3D) movie display with a mechanically rotating light emitting diode (LED) line display has been reported [2], but it's resolution and color resolution are insufficient for an anthropomorphic agent. Head-mounted displays [3] and planar holographic displays can overcome this problem, but they restrict users' viewpoints.

We have developed a novel display on which an agent is visible from any viewpoint. The display consists of a spherical mirror and a cylindrical rear screen. Light emitted from an image projector is reflected by the spherical mirror and projected on the inside of the screen. This display, when combined with computer graphics techniques, enables 3D agent actions. For example, the agent can turn to a person, and the system notifies her that the agent's attention is now focused on her. Using this technique, more natural communication among the agent and users in a 3D environment can be realized. The display is suitable for an omnidirectional telecommunications system.

Fig. 1. Appearance of the display.

2. CYLINDRICAL DISPLAY

2.1. Structure

Figure 1 shows the appearance of the cylindrical display, and Fig. 2 it's structure.

We drew some omnidirectional panoramic images. Figure 3 shows an example. To display such a panoramic image on the cylindrical display, we have to transform it into the projection image shown in Fig. 4. The calculation method for doing so is described in Sec. 2.2. As Fig. 3 illustrates, light emitted from an image projector at the bottom is reflected by a spherical mirror at top and the reflected light is projected on the inside of the cylindrical rear projection screen.

The optical path length from the projector to the screen is quite different depending on the screen position. It would be difficult to produce an image in clear focus over the entire screen with ordinary lenses. We therefore analyzed the optical path length and designed a special lens

We made $R = 12.5$ cm, $L_2 - L_1 = 30$ cm, and designed the projection lens under the constraint that any position L from L_1 to L_2 is in focus. For this prototype display,

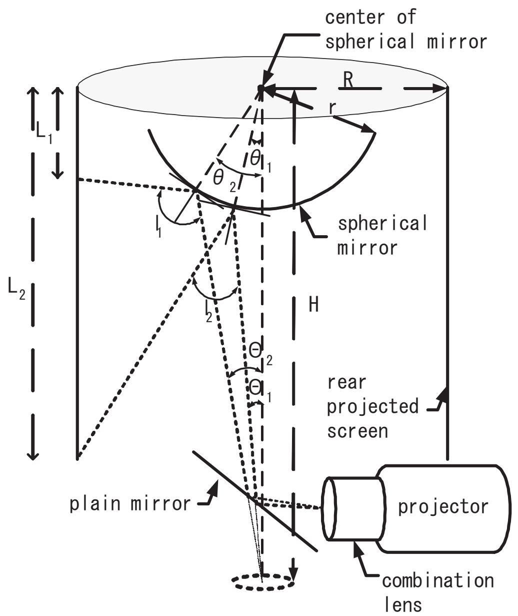


Fig. 2. Structure of the display.

Fig. 3. An omnidirectional panoramic image

Fig. 4. A projection image.

we selected a SONY VPL-PX15 projector and replaced its lens with our specially designed combination lens (F $= 3.0$ mm, f $= 60.88$). The other parameters are $\Theta_1 = 2.9°$, $\Theta_2 = 9.4°$, $\theta_1 = 10.1°$, $\theta_2 = 28.9°$, $H = 55.5$ cm, $r = 15.5$ cm (Fig. 2). The rear screen is a soft screen [1] whose diffusion coefficient for transmitted light is high, and images on the screen are seen uniformly in brightness and color from various viewpoints.

2.2. Projection image generation

The method of generating images is shown in Fig. 5. Let projection images be described by polar coordinates (r, θ) and panoramic images be described by orthogonal coordinates (X, Y). A pixel $P(r, \theta)$ on the projection image is projected to $P'(f(\theta), g(r))$ on the panoramic image:

$$f(\theta) = \theta \cdot \frac{X_{max}}{2\pi}, \quad (1)$$

$$g(r) = g(R_a) + (r - R_a) \cdot \frac{g(R_b) - g(R_a)}{R_b - R_a} \quad (2)$$

To decide $g(r)$, sample points with different r were projected on the screen and Y coordinates were measured, and linear interpolation was used for intermediate r.

When the display receives omnidirectional images in real time, the translation is executed not by each pixel of omnidirectional panoramic images but by each rectangle in them. Image warping, which greatly accelerates execution by computer graphics hardware, is used for the translation of each rectangle on omnidirectional panoramic images (Fig. 6).

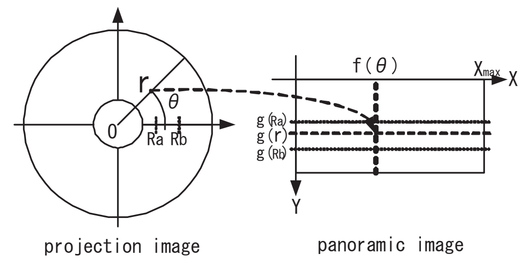


Fig. 5. Correspondence between images.

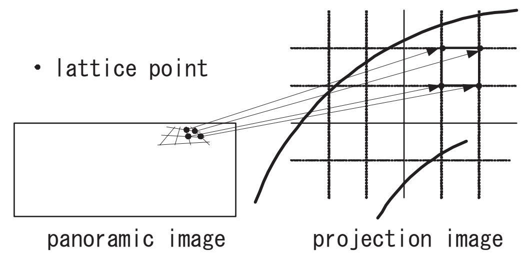


Fig. 6. Image warping method.

3. EXPERIMENTAL RESULTS

We evaluated the display's resolution, intensity, and contrast. All are uniform on the circumference with the same height, but they vary depending on height.

3.1. Resolution

Figure 7 shows the vertical and horizontal resolution along screen height. The projected image is reflected by the spherical mirror and the resultant image is deformed in both vertical and horizontal directions. Some parts of the image are more stretched than others. The resolution is thus position

[1]KIKUCHI SCIENCE LABORATORY INC. rear soft standard 180 (RS13K)

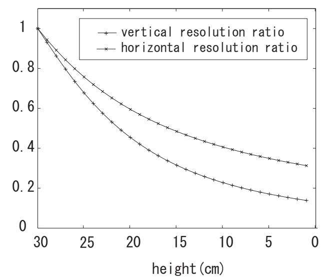


Fig. 7. Resolution along screen height.

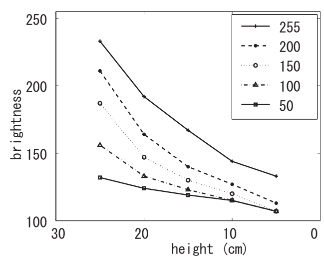


Fig. 8. Brightness of various height.

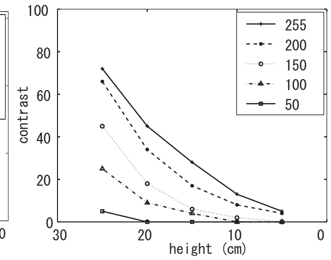


Fig. 9. Contrast of various height.

dependent. We evaluated the vertical and horizontal resolution on the screen.

When the light's incident angle on the screen is near normal, the projected region on the screen from a pixel on the LCD of the projector is small and has higher resolution, whereas, when it is small, the projected region is large and has lower resolution.

A circle with diameter r and it's center at the origin of the projection image is projected to horizontal line $Y = g(r)$ on the panoramic image. As the screen width is constant along the horizontal circumference and the number of pixels of the circle is proportional to r, the horizontal resolution is proportional to r. Inner circles are projected to lower parts of the screen, and outer circles to upper parts. Therefore, horizontal resolution becomes low at lower parts of the screen.

3.2. Brightness and contrast

Brightness and contrast were evaluated in a room environment with the light on. A filled gray-level circle was projected on the screen and its image captured by a camera (SONY DFW-SX900). Brightness is defined as the captured gray-scale value, which has range from black (0) to white (255). Contrast C(P)of the position P is defined as

$$C(\mathrm{P}) = V(\mathrm{P}) - \bar{V}(\mathrm{P}) \qquad (3)$$

where $V(\mathrm{P})$ is brightness of P and $\bar{V}(\mathrm{P})$ brightness of P's neighboring position, which has a black color.

Circle positions are represented by cylindrical coordinates (α, d, h) whose origin is the center of the circle at the bottom and whose rotation axis is the vertical line through the origin. The α is the rotation angle, d is the distance from the rotation axis, and h is the height on the rotation axis from the origin.

Small filled circles (same size) were drawn at 25-, 20-, 15- and 10-cm height. The gray scale values were 255, 200, 150, 100 and 50. The brightness and contrast of the circles were measured. Brightness is shown in Fig. 8 and contrast is shown in Fig. 9. Brightness decreases with decreasing resolution. When it was close to 100, the contrast becomes fairly small because the room brightness has a similar value. When the result of contrast was checked, darker and lower circle was found not to be distinct from room brightness. Subjectively, when the contrast was lower than 5, the circles were not distinct.

3.3. Viewing angle

If the display screen diffuses transmitted light in all directions equally, the image on the screen can be observed uniformly at any viewing angle. If the screen does not diffuse light equally, the viewing direction is limited to that of the light direction.

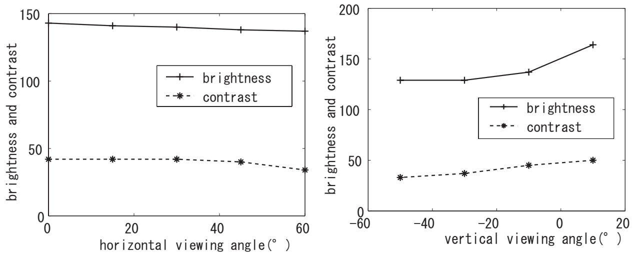
3.3.1. Horizontal viewing angle

A white circle was projected at $h = 20$ on the screen. The camera was set at $d = 60$, $h = 10$. The brightness and contrast of the circle were measured at four horizontal viewing angle ($\alpha = 15°$, $30°$, $45°$, $60°$). As shown in Fig. 10 (a), the brightness and contrast stayed almost constant over the horizontal viewing angle of 60 degrees.

3.3.2. Vertical viewing angle

The light's incident angle to the screen is greatly different between the bottom and top. Vertical differences between the light direction and viewing direction raise the possibility of a visible brightness difference.

A white circle was projected at $(h = 20\mathrm{cm})$ on the cylinder's surface. The camera was set at a various tilt angles ($+10°$, $-10°$, $-30°$, $-50°$) toward the circle. As shown in Fig. 10(b), both the brightness and contrast of the image were highest at the tilt angle of 10 degrees. This is because the projection image is reflected by the spherical mirror downward and the angle between the light direction and the viewing direction becomes minimum. In normal use, the tilt angle may be around $0 \sim 20$ degrees and the brightness and contrast of the image will stay almost constant. If the positions of the projector and the spherical mirror are reversed, the viewing characteristics will be reversed.



(a) Horizontal viewing characteristics. (b) Vertical viewing characteristics.

Fig. 10. Viewing angle characteristics.

4. APPLICATIONS

4.1. Anthropomorphic agents communicating with several people at once

The anthropomorphic agent system has an omnidirectional image sensor [4] and an eight-microphone array on top of the cylindrical display. The image sensor subsystem detects people in the room. An auditory subsystem detects a person's utterance and determines the direction of the sound source. On the basis of the people's position information and sound direction information, the system determines the person with whom it will communicate, turns the agent's face to that person, and notifies her of it's intention to communicate.

4.2. Bidirectional tele-communications system using omnidirectional images

For communication with several people at distant places, omnidirectional images are very useful because they can share all views. Conventional telecommunications system using an omnidirectional imaging sensor and head-mounted display [5] can not always accomplish bidirectional telecommunication because the head-mounted display may hide the subtle facial expressions essential to human communication. The proposed system can capture several people with its omnidirectional imaging sensor and show a tele-omnidirectional mirror image on the cylindrical display. Figure 11 shows bidirectional telecommunication taking place by means of omnidirectional image sensing on the proposed display.

5. CONCLUSION

This paper proposed a small cylindrical display for anthropomorphic agents. We evaluated our display by measuring the brightness of pixels at various point on the screen and at various viewing angles. At the lower part of the screen, the brightness and contrast of pixels are weaker than at the upper part. Visibility is not affected by horizontal viewing angle. The image appears slightly bright when viewed at

Fig. 11. Bidirectional tele-communications system using omnidirectional images.

an upward angle. Farther research is needed to improve the uniformity of these imaging characteristics. If plural agents on the screen and sound source separation techniques are incorporated, the system will be able to communicate with multiple users concurrently.

6. ACKNOWLEDGMENTS

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