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Immersive Autostereoscopic Display for Mutual Telexistence: TWISTER I (Telexistence Wide-angle Immersive STEReoscope model I)

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Abstract

We present an autostereoscopic display named TWISTER I (Telexistence Wide-view-angle Immersive STEReoscope, Model I), which is designed for a face-to-face tele-communication system called "mutual telexistence." By rotating display units that consist of LED arrays and a barrier around a viewer, TWISTER I can display panoramic stereoscopic images that can be observed without the use of special eyewear. This "glassless" feature is essential for applying this apparatus to mutual telexistence because eye contact is important in non-verbal communication.

1 Introduction

Development of a system that allows for face-to-face communication between remote users has long been a challenging concept. Our team is also studying such a system called "mutual telexistence." [7],[8],[14]. The concept is shown in Figure 1 Although there are still some technical problems to be solved, this paper focuses on a visual display.

The visual display is required to provide realistic three-dimensional images that enables users to sfeel as if they were sharing an environment. Recently, some studies employ immersive projection technology (IPT) such as CAVE[3] that can generate wide view-angle stereoscopic views. However, this kind of displays demands that viewers wear special eyeglasses that cover a viewer's eyes and prevents eye contact between its users. This situation is undesirable, since facial expressions, particularly around the eyes, are an essential part of face-to-face communication. On the other hand, conventional autostereoscopic (glassless stereoscopic) displays do not have a viewing-angle that is sufficient for mutual telexistence in a situation such as, for example, a cocktail party. Unlike a round-table talk, many other participants surround a participant. . Thus, a wide-angle, stereoscopic display that is not dependent on special eyewear is optimal for mutual telexistence.

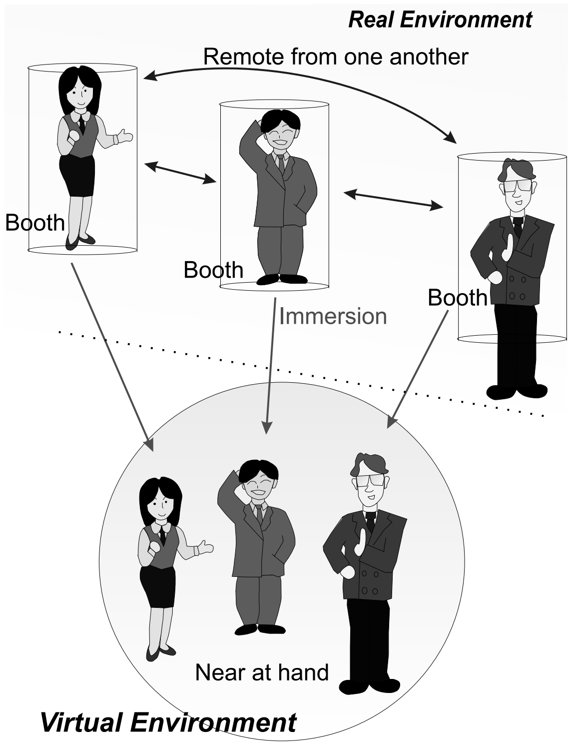

Figure 1. Concept of Mutual Telexistence

To satisfy the demands noted above, a novel autostereoscopic display system was constructed. It is called TWISTER I (Telexistence Wide-angle Immersive STEReoscope, Model I). By mechanically rotating display units that consist of LED arrays and a barrier around a viewer, TWISTER I can display very wide-angle stereoscopic images that can be perceived without the use of special eyewear.

2 Related Work

Parallax barrier is one of the most common methods for autostereoscopic display. This method seems to have been invented in the early 20th century by F. E. Ives and has been studied by several researchers[11]. The method makes use of striped images for each eye. The images are spatially multiplexed on a screen, and very fine vertical slits are located between the observer and the screen. By viewing these images through vertical slits, only the left images can be observed with the left eye and the right images with the right eye. The displays that use lenticular lenses instead of slits [6],[10] and place slits between a backlight and a liquid crystal panel [5] are also in this category.

However, there are two well-known disadvantages to such displays. First, the eye position of the observer is strictly limited; thus, head motion is restricted to a few fixed positions or a relatively narrow region. Secondly, horizontal spatial resolution of the screen is divided so that each eye perceives only one half of the screen.

To address the first problem, some displays adjust the positions of lenticular lenses [2] or light sources [12] according to the observer's head motion; however, there seems to be room for improvement of the tracking speed.

On the other hand, some display systems employ a periodic barrier motion that is not similar to the tracking motion mentioned above. Since a dynamic barrier motion works as a time-multiplexor, each eye perceives the whole screen. Records say the cyclostereoscope by F. Savoye was demonstrated at Luna Park in Paris in 1949. Recently, the cyclostereoscope has been revived[1]. The apparatus consists of a screen with a rotating fence around it, and the left and right images are projected from outside. Because a fence horizontally interlaces both of the projected images, the viewers outside the rotation can see stereoscopic images through the apertures in the fence. If the rotating speed were fast enough, the viewers would perceive no flicker. Although the cyclostereoscope provides only a pair of parallax images, TAO (Telecommunications Advancement Organization of Japan) constructed a similar display capable of multiple parallax images [4]. Also, Homer B. Tilton produced the parallactiscope in which a vertical slit scans horizontally in front of a CRT (cathode-ray tube) [15]. Furthermore, some recent experiments employ an electronic barrier instead of a mechanical one [13].

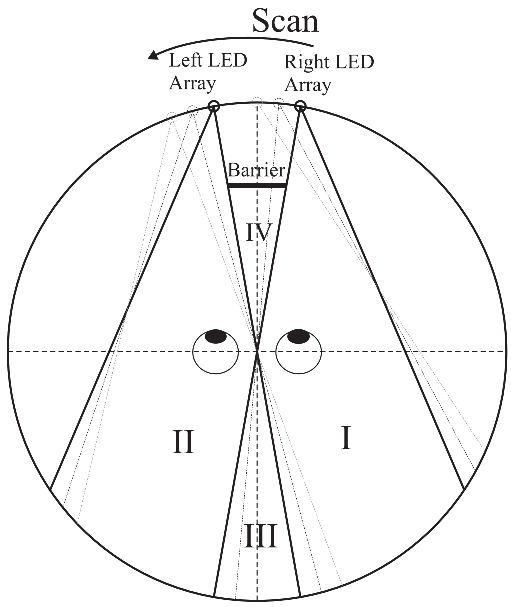

Figure 2. Principle of Movable Parallax Barrier Method (Top View)

3 Principle

3.1 Movable Parallax Barrier

Figure 2 shows the method *movable parallax barrier* that we have used. The basic idea is to scan a pair of directional light sources, each of which is visible to one eye only. To produce directional light sources, a pair of vertical LED arrays and a vertical barrier are combined. By rotating them around the observer as a single display unit, the apparatus can present cylindrical images that are separately perceived by each eye. Thus, the observer can experience wide-angle stereoscopic images without special eyewear.

In Figure 2, the right and left eyes need to be in region I and II, respectively, for stereoscopic viewing. Region III is a "cross-talk" region, where both images are visible, and both images are visible in region IV. By design, regions I, II, II, and IV intersect at the center of the circle so that the apparatus permits a relatively wide range of head movement.

3.2 Viewing Areas

Each eye should be located in a specific area as the display unit rotates. First, let R be the radius of a display, ω the beam angle of a light source, γ the viewing-angle of a barrier from the center, and θ the rotating angle of a display unit, as shown in Figure 3. The condition in which only the

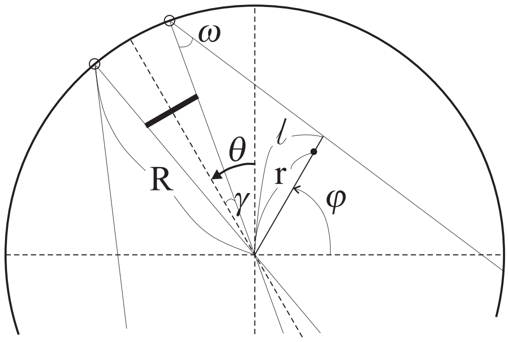

Figure 3. Variables for Calculation of Viewing Areas

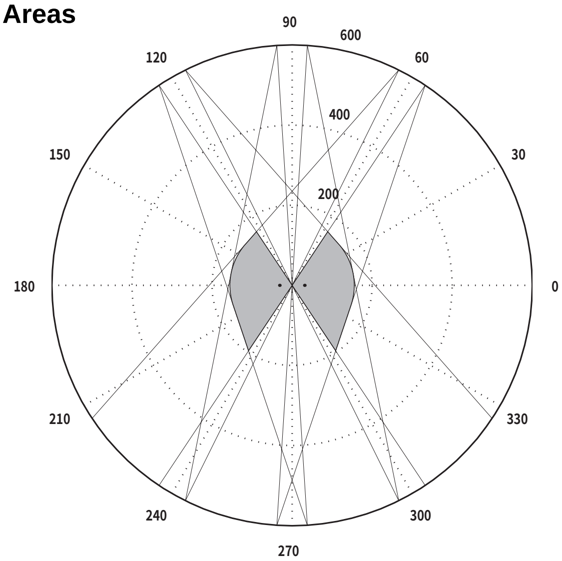

Figure 4. Calculated Viewing Areas. The black dots indicate typical eye positions (interocular distance: 6.25cm).

light for the right eye is visible at the position (r_0, ϕ_0) is

$$r_0 \leq l(\theta, \phi_0) \quad (1)$$

,where $l(\theta, \phi)$ is the length between the center of the circle and region I at angle ϕ. Then, if a display unit moves within the range $-\Delta\theta \leq \theta \leq \Delta\theta$, r_0 must satisfy the following condition:

$$r_0 \leq \min_{-\Delta\theta \leq \theta \leq \Delta\theta} l(\theta, \phi_0) \quad (2)$$

By substituting $l(\theta, \phi) = l(0, \phi - \theta)$,

$$\begin{aligned} r_0 &\leq \min_{-\Delta\theta \leq \theta \leq \Delta\theta} l(0, \phi_0 - \theta) & (3) \\ &= \min_{\phi_0 - \Delta\theta \leq \phi \leq \phi_0 + \Delta\theta} l(0, \phi)\ (where \phi \equiv \phi_0 - \theta) & (4) \end{aligned}$$

Furthermore, by using

$$l(0, \phi) = \begin{cases} 0 & -\pi \leq \phi < -\frac{\pi}{2} + \gamma \\ R & -\frac{\pi}{2} + \gamma \leq \phi < -\frac{\pi}{2} + 2\omega - \gamma \\ R \cdot \frac{\sin\omega}{\sin(\frac{\pi}{2} + \phi + \gamma - \omega)} & -\frac{\pi}{2} + 2\omega - \gamma \leq \phi < \frac{\pi}{2} - \gamma \\ 0 & \frac{\pi}{2} - \gamma \leq \phi < \pi \end{cases} \quad (5)$$

(when $\omega > \gamma$), we obtain the region shown in Figure 4 that satisfies equation (4). In Fugure 4, the actual parameters of TWISTER I ($R = 600[mm]$, $\omega = 15°$, $\gamma = 3.63°$, $\Delta\theta = 30°$) are applied. The black dots indicate typical eye positions (interocular distance: 6.25cm).

3.3 Time-Space Tradeoff

Let $f[\mathrm{Hz}]$ be the frame rate of the images, n the pixels per round, $F[\mathrm{Hz}]$ the driving frequency of the light source, N the number of the display units and $\nu[\mathrm{rad/s}]$ the angular velocity of the display units. $\frac{1}{f}$ seconds after one display unit passes at a point on the circle and refreshes the pixel there, the next display unit pass the same point and refresh the pixel. As the angle between the display units is $\frac{2\pi}{N}$,

$$\frac{1}{f} = \frac{2\pi}{N} \cdot \frac{1}{\nu}. \quad (6)$$

Also, the display unit takes $\frac{2\pi}{\nu}$ seconds to go around and the light source refreshing F times per second. Therefore,

$$n = F \cdot \frac{2\pi}{\nu}. \quad (7)$$

Then, by equation (6),(7),

$$f \cdot n = F \cdot N \quad (8)$$

is established. This indicates a tradeoff relationship in which the product of the resolutions of time and space is constant. The right part indicates a situation in which the display units are static. When we use LED as a light source, F can be much bigger than the frame rate required by humans; whereas, very fine slit processing such as that used in a conventional parallax barrier is required to get enough N. However, sufficient time resolution can be compensated for deficient space resolution by dynamically scanning the display units.

4 Implementation

4.1 Specification

Figure 5 shows an overview of the first prototype TWISTER I (Telexistence Wide-angle Immersive STEReoscope, Model I). Display units are attached to a hexagonal

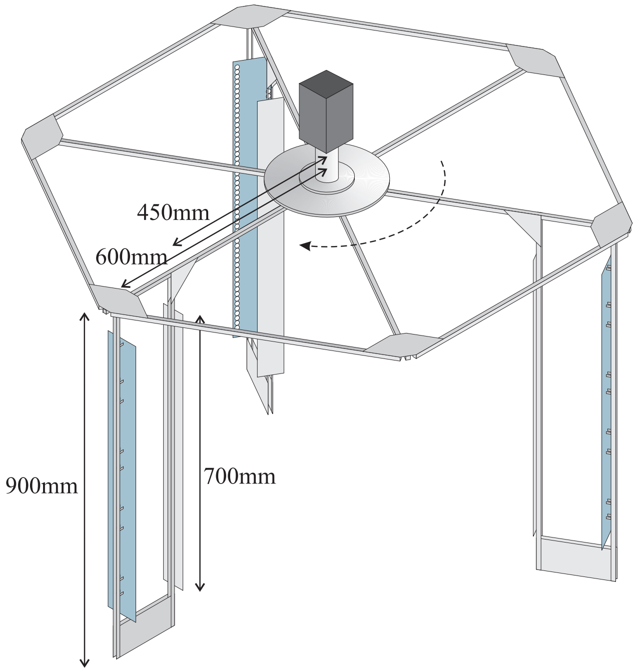

Figure 5. Overview of TWISTER I (Telexistence Wide-angle Immersive STEReoscope, Model I)

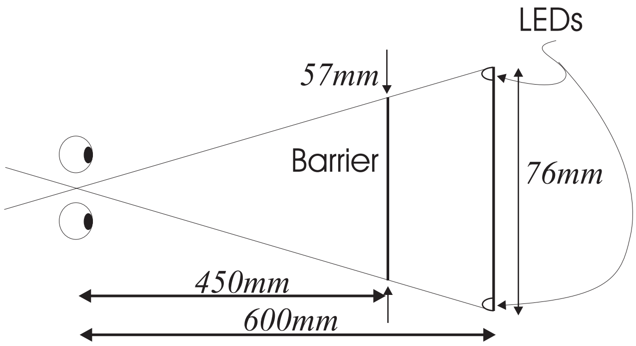

Figure 6. Layout of the LED arrays and the barrier

Figure 7. Photograph of TWISTER I

frame that is rotated by an AC servomotor. The hexagonal frame is made of aluminum, which is light and solid enough to rotate about $1 \sim 3$ round per second. To each vertex of this frame, a display unit could be attached; however, three of them have been attached in every other vertex to date.

The AC servomotor (Oriental Motor KBLM460GD-A) rotates this frame at a rate of about one round per second (60rpm). Since the rated speed is 3000rpm, a 10:1 gearbox is attached to slow the speed.

Each display unit consists of two columns of LED arrays and a thin aluminum barrier. One vertical line has 128 red LEDs, 32 of which are controlled by one microcomputer. A vertical view angle is $57°$ when the observer is located at the center. Horizontally, 960 dots can be displayed per round, although the view-angle and visible regions mentioned previously have a tradeoff relationship. To date, 160x128 monochrome images ($60° \times 57°$) are restored in the EEPROM on the microcomputer and displayed. Three display units are rotated at one round per second. Thus, the refresh rate of the images is three frames per second by equation 6.

The layout of the LED arrays and the barrier is shown in Figure 6. The line connecting the edges of the barrier and the LED intersects at the center of the apparatus. This arrangement contributes to minimizing a *cross stalk* region where both LED arrays are visible.

4.2 Experiment

In Figure 7, an observer views stereoscopic images without eyewear. A helmet is worn for safety and does not contribute to the stereoscopic view; however, a transparent acrylic guard will be used in the future. Due to mechanical barrier scanning, the left and right images are completely isolated; thus, a so-called *ghosting* artifact that is common in polarization-based stereoscopic displays is hardly observed. Moreover, the barrier is not perceivable because of its speed. Also, the rotation of the frame is quite stable and quiet so that observers can enjoy noticeably clear stereoscopic images.

As an experiment, the images shown in Figure 8 were displayed. Since the disparity of the lower square is larger than that of the upper one, the lower one should be per-

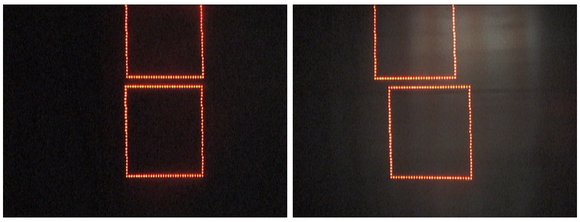

Figure 8. Stereoscopic test pattern. The left image for the left eye, the right image for the right eye, respectively.

ceived as deeper. When we tested the 10-male/female subjects, all of them correctly answered which square is the deeper.

5 Future Work

There are short- and long-term plans for the continuation of this study.

Short-term work will focus on improving the basic quality of TWISTER as a three-dimensional display. First, full-color displays are indispensable for realism. This might be achieved by replacing the current monochrome red LEDs with full-color LEDs; however, rotating separate red, green, and blue LEDs would be a lower-cost implementation. If the rotation speed is fast enough, the observer will perceive mixed color. Second, the display of images in motion is also essential. To achieve this, we have to transmit image data to rotating display units instead of restoring them in the on-chip memory of a microcomputer. For our next prototype TWISTER II, we will employ wired data transmission using a slip ring, although wireless transmission is an attractive choice. Third, head tracking would be necessary to widen a visible area and provide motion parallax. Although the visible area of the current system is relatively wide compared to conventional parallax barrier displays, an observer's motion is restricted near the center of the booth. Also, motion parallax is crucial for providing three-dimensional space as well as a stereoscopic view. Lastly, of course, we cannot neglect safety. Currently, some users would be frightened by aluminum barriers rotating at relatively fast speeds in front of their faces without a guard. Therefore, we will place a large acrylic cylinder in-between the observer and the rotator.

Besides all these specific improvements, we intend to add a new twist to this apparatus. In our mutual telexistence, one user sees other users and is simultaneously seen by them. To satisfy this bi-directional nature, the booth will display stereoscopic figures of the other users and capture the image of the user within. This can be achieved by placing cameras between display units and rotating them. FFurthermore, once these images from various viewpoints around the user are obtained, a new view can be constructed from an arbitrary viewpoint in real-time by our previously proposed technique[7],[8]. When each booth provides a reconstructed view from a viewpoint in a virtual environment, this situation achieves *mutual telexistence*.

6 Conclusion

This paper presented a new autostereoscopic display TWISTER I (Telexistence Wide-angle Immersive STERe-osope, Model I), which can provide wide-angle stereoscopic images without requiring the use of eyewear. The implementation of this apparatus is simple. It requires rotating display units consisting of two columns of LEDs and a barrier around the observer. Besides, if cameras are rotated together, the human figures from all directions can be captured simultaneously. Although the current prototype is immature, the feasibility of mutual telexistence can be demonstrated.

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