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# Two Ways of Mutual Telexistence: TELESAR and TWISTER

Susumu TACHI, Ph.D.
*The University of Tokyo*
*Department of Information Physics & Computing*
*7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656 Japan*
http://www.star.t.u-tokyo.ac.jp/

**Abstract**. Telexistence (tel-existence) is fundamentally an advanced type of teleoperation system that enables an operator at the control to perform remote tasks dexterously with the feeling that he or she exists in a surrogate robot that is working in the remote environment. It is also a concept named for the general technology which enables a human being to have a real-time sensation of being at a place other than where he or she actually exists, and is able to interact with the remote and/or virtual environment, where surrogate robots can be virtual. Conventional telexistence systems provide an operator the real-time sensation of being in a remote environment, although persons in the remote environment have only a feeling that a surrogate robot is presented, not the operator. Mutual telexistence aims at solving this problem so that the existence of the operator is apparent by the persons in the remote environment by providing mutual sensations of presence.

This paper reviews how the original telexistence technology has been developed, and describes two newly developed methods of mutual telexistence. The first projects real-time images of the operator on the surrogate robot by applying HMP (Head Mounted Projector) technology, and the second uses a virtual surrogate presented by an immersive full-color

autostereoscopic display dubbed TWISTER (Telexistence Wide-angle Immersive STEReoscope).

## Introduction

Telexistence (tel-existence) is a technology that enables us to control remote objects and communicate with others in the remote environment with a real-time sensation of being there by using surrogate robots, remote/local computers and cybernetic human interfaces. This concept has been expanded to include projection of ourselves into computer-generated virtual environments, and also the use of a virtual environment for the augmentation of the real environment.

The author proposed the concept of the telexistence in 1980 and the concept of telexistence played the role of the fundamental principle of the eight year Japanese National Large Scale Project of "Advanced Robot Technology in Hazardous Environments," which started in 1983 together with the concept of Third Generation Robotics. Through this project, researchers made theoretical considerations, established systematic design procedures, developed experimental hardware telexistence systems, and demonstrated the feasibility of the concept.

Thanks to the efforts of twenty years of research and development, it has nearly become possible for a human to use a humanoid robot in the remote environment as if it was his/her other self, i.e., (s)he is able to have the sensation that (s)he is just inside the robot in the remote environment. Although existing telexistence systems succeeded in providing an operator a real-time sensation of being in a remote environment, persons in the remote environment did not have the feelings that the human operator is presented, but only a surrogate robot.

Mutual telexistence aims at solving this problem so that the existence of the operator is apparent by the persons in the remote environment by providing mutual sensations of presence.

This paper reviews the original telexistence technology, and introduces two methods of mutual telexistence. The first uses projection of real-time images of the operator on the surrogate robot, based on HMP (Head Mounted Projector) technology. The second uses an image-based virtual surrogate, which is presented by an immersive full-color autostereoscopic display dubbed TWISTER (Telexistence Wide-angle Immersive STEReoscope).

# 1. Short History of Telexistence

Figure1 shows the concept of telexistence in real environments, virtual environments, and the real environment through a virtual environment (augmented telexistence). The following describes the research and development conducted in order to realize the concept.

Our first report [1] proposed the principle of the telexistence sensory display, and explicitly defined its design procedure. The feasibility of a visual display with a sensation of presence was demonstrated through psychophysical measurements using experimental visual telexistence apparatus.

A method was also proposed to develop a mobile telexistence system that can be driven remotely with both an auditory and visual sensation of presence. A prototype mobile televehicle system was constructed and the feasibility of the method was evaluated [2].

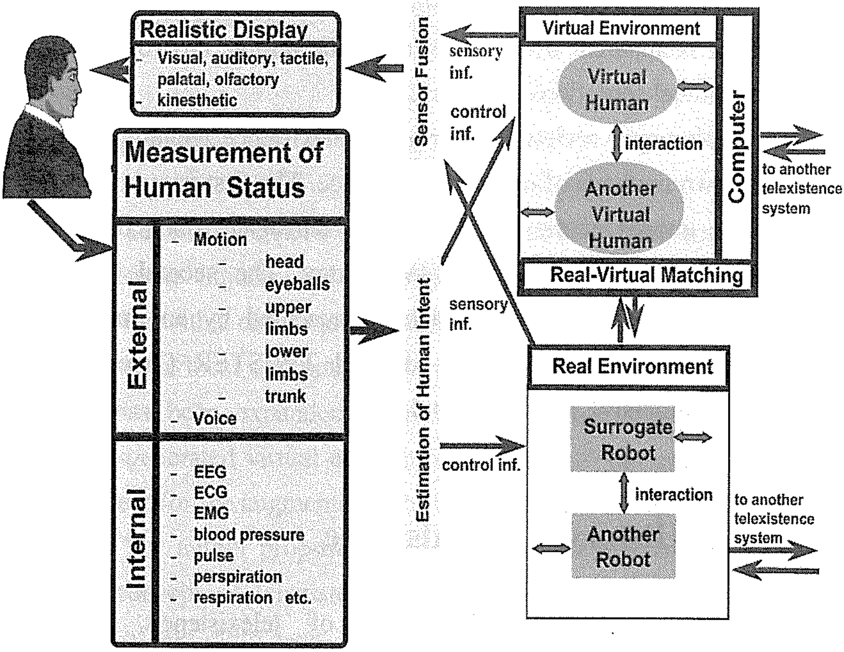


**Figure 1:** Concept of Telexistence.

In 1989, a preliminary evaluation experiment of telexistence was conducted with the first prototype telexistence master slave system for remote manipulation. An experimental telexistence system for real and/or virtual environments was designed and developed, and the efficacy and superiority of the telexistence master-slave system over conventional master-slave systems was demonstrated experimentally [3, 4, 5].

Augmented telexistence can be effectively used in numerous situations. For instance, to control a slave robot in a poor visibility environment, an experimental augmented telexistence system was developed that uses a virtual environment model constructed from design data of the real environment. To use augmented reality in the control of a slave robot, a calibration system using image measurements was proposed for matching the real environment and the environment model.

The slave robot has an impedance control mechanism for contact tasks and to compensate for errors that remain even after the calibration. An experimental operation in a poor visibility environment was successfully conducted by using a humanoid robot called TELESAR (TELExistence Surrogate Anthropomorphic Robot) (Figure 2) and the virtual TELESAR. Figure 3 shows the virtual TELESAR used in the experiment and Figure 4 shows the master system for the control of both real TELESAR and virtual TELESAR [6,7,8,9].

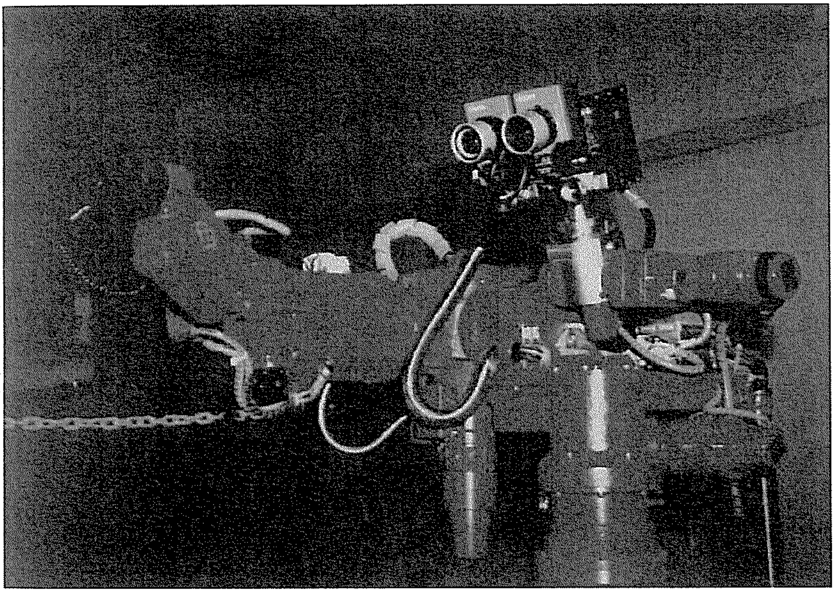

**Figure 2:** Telexistence Surrogate Anthropomorphic Robot (TELESAR) at Work (1988).

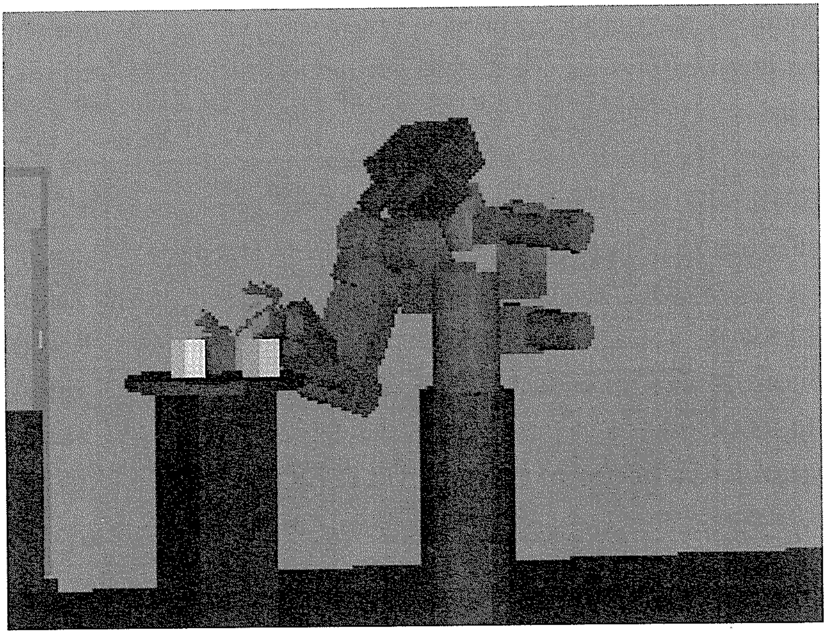

**Figure 3:** Virtual TELESAR at Work (1993).

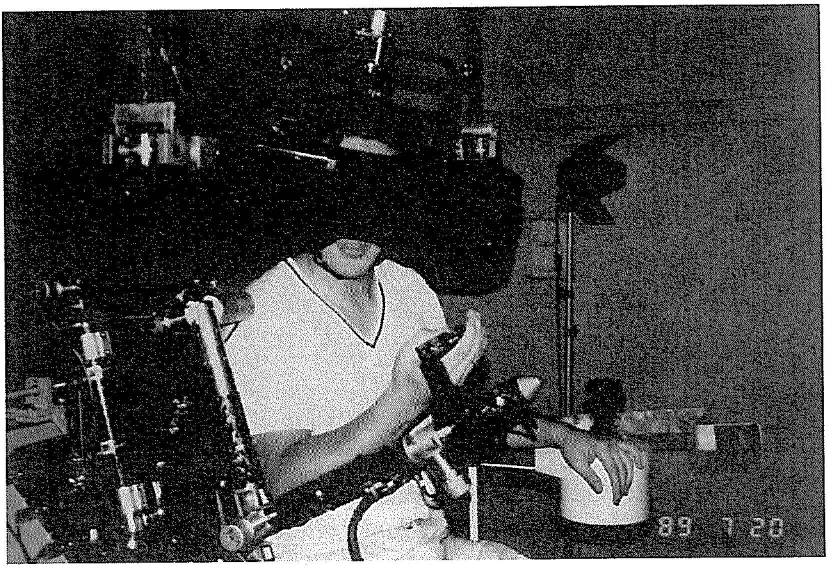


**Figure 4:** Telexistence Master (1989).

Experimental studies of tracking tasks demonstrated quantitatively that a human being can telexist in a remote environment and/or a computer-generated environment by using the dedicated telexistence master slave system [5].

For METI's national five year HRP (Humanoid Robotics Project:1998-2003), telexistence technology was adapted in a new type of cockpit system to control a humanoid biped robot, as shown in Figure 5. The telexistence cockpit was developed for this project in March 2000 (Figure 6). It consists of three main subsystems: an audio/visual display subsystem, a teleoperation master subsystem, and a communication subsystem between the cockpit and the humanoid robot [10,11,12].

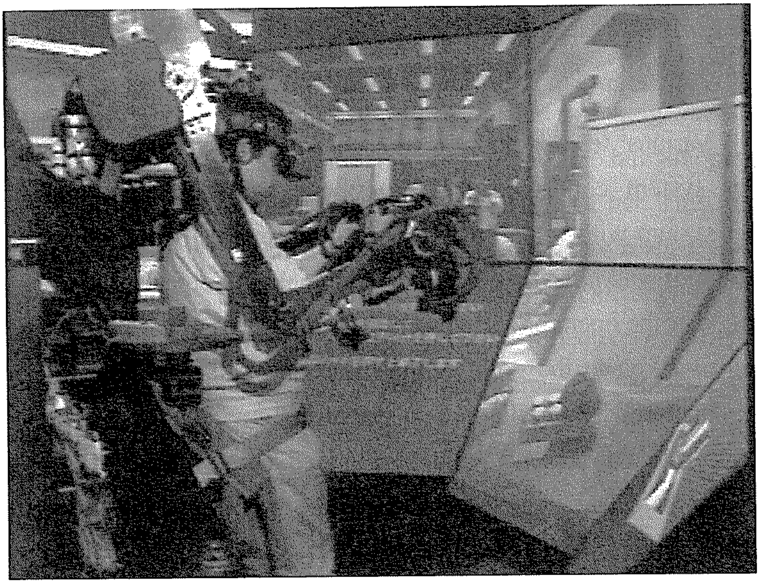

**Figure 5:** Telexistence Cockpit for Humanoid Control (2000).

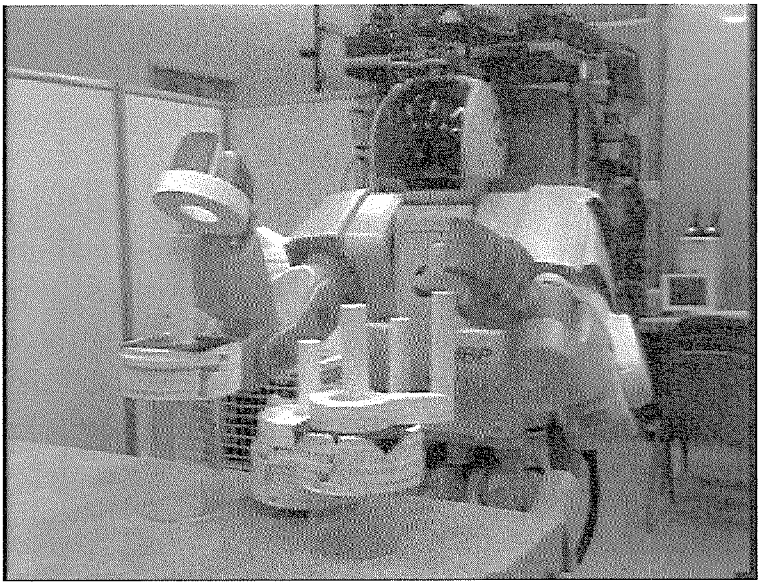

**Figure 6:** HRP Humanoid Robot at Work (2000).

Various teleoperation tests using the developed telexistence master system confirmed that kinesthetic presentation through the master system with visual imagery greatly improves both the operator's sensation of walking, and dexterity at manipulating objects.

If the operator issued a command to move the robot, the robot actually walked to the goal. While the robot walked around, the real images captured by a multi-camera system for a wide field of view were displayed on four screens of the surrounded visual display. This made the operator feel as if they were inside the robot, walking around the robot site.

A CG model of the robot in the virtual environment was represented and updated according to the current location and orientation received from the real robot. It was displayed on the bottom-right screen of the surround visual display, and when augmented to the real images captured by the camera system, it supported the operator's navigation of the robot.

Since the series of real images presented on the visual display are integrated with the movement of the motion base, the operator feels the real-time sensation of walking, or stepping up and down.

Through these efforts of more than twenty years, it has become nearly possible for a human to use a humanoid robot in the remote environment as if it were his/her other self. Persons can control the robot by just moving their body naturally, without using verbal commands. The robot follows just the same way as the person moves, and through the sensors on board the robot the human can see, hear and feel as if they sensed the remote environment directly. Persons can virtually exist in the remote environment without actually being there in a sense.

For persons in the remote environment, however, the situation is different. They see only the robot moving and speaking. Although they can hear the voice and witness the behaviour of the human operator through the robot, it does not actually look like him or her. This means that the telexistence is not yet mutual. In order to realize mutual telexistence, we have been pursuing two approaches. One approach uses head mounted projection technology with retro reflective material as a screen, and the other uses a wide-angle immersive booth dubbed TWISTER.

## 2. Robotic Mutual Telexistence

Twenty years have passed since our first idea and concept of telexistence, and it is now possible to telexist in the remote and/or virtual environment with a sensation of presence. We can work and act with the feeling that we are present in several real places. However, in the location where the user telexists, people see only the robot but cannot feel that the person is actually present. Simply placing a TV display on board the robot to show the face of the user is not very satisfying, since it appears mostly comical and far from reality.

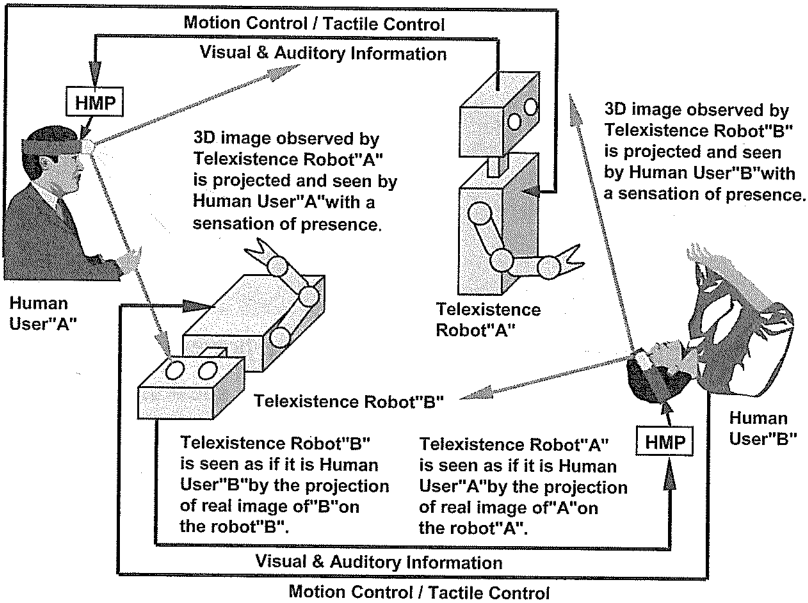


**Figure 7:** Concept of Robotic Mutual Telexistence (adopted from [13]).

Figure 7 illustrates the proposed method of mutual telexistence using HMP and a retro-reflective screen to make a telexisted robot look like its user. This is an effort toward the next generation of telexistence [13, 14,15].

In our laboratory at the University of Tokyo, a new type of visual display is being developed called X'tal (pronounced crystal) vision [16, 17], which uses retro-reflective material as its screen. A projector is arranged at the conjugate position of a user's eye, with a pinhole placed in front of it to ensure adequate depth of focus. Images are projected onto a screen that is either made, painted, or covered with retro-reflective material [17].

The retro-reflector screen, together with the pinhole, ensures that the user always sees images with accurate occlusion relations. This means that if the user's body has a retro-reflector on it, their body becomes a part of the virtual environment and disappears, replaced by a virtual body. A body without a retro-reflector on it will occlude the virtual environment without a troublesome shadow obscuring the virtual environment.

In the construction of X'tal vision, screen shapes are arbitrary, i.e., any shape is possible. This is due to the characteristics of the retro-reflector, and the pinhole in the conjugate optical system. By using the same characteristics of X'tal vision, binocular stereovision becomes possible using only one screen with an arbitrary shape. The projector can be mounted on the head of a user, which we call an HMP (Head Mounted Projector) System.

Suppose a human user A uses his telexistence robot A' at the remote site where another human user B is present. The user B in turn uses another telexistence robot B', which exists in the site where the user A works. 3-D images of the remote scenery are captured by cameras on board both robots A' and B' are sent to the HMPs of human users A and B, respectively, both with a sensation of presence. Both telexistence robots A' and B' are seen as if they were their respective human users by projecting the real image of the users onto their respective robots.

Figure 8 presents an example of how mutual telexistence can be achieved through X'tal vision. Figure 8(A) shows a miniature of the HONDA Humanoid Robot, while Figure 8(B) shows the robot painted with retro-reflective material. Figures 8(C) and (D) show how they appear to a human wearing an HMP. The telexisted robot looks just like the human operator of the robot, and telexistence can be naturally performed [13]. We are currently in the process of a feasibility study for the proposed method using TELESAR.

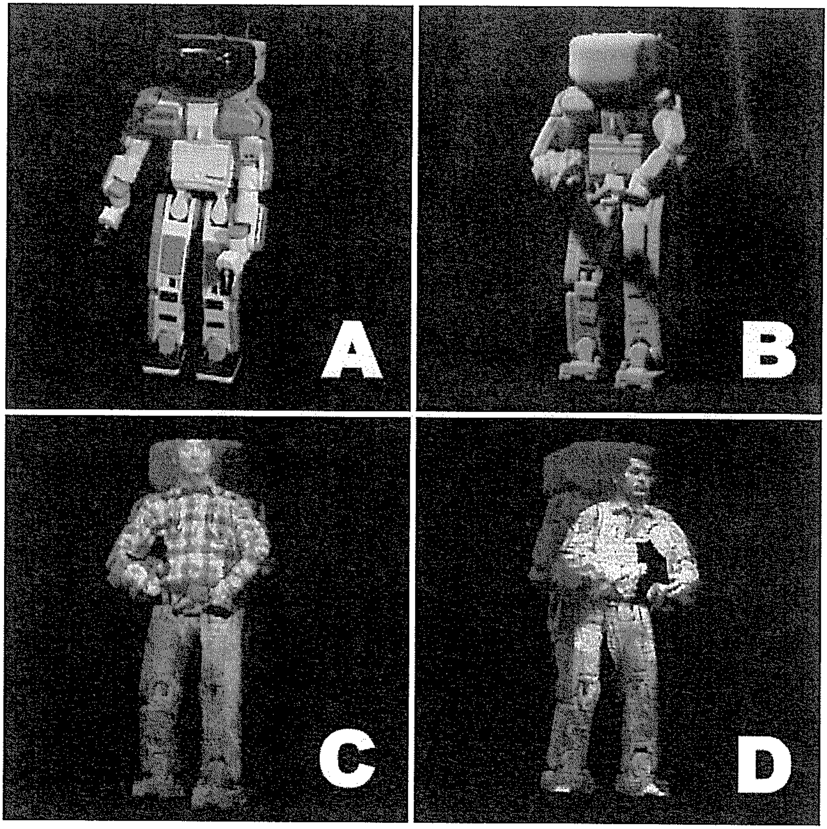


**Figure 8:** (A) Miniature of the HONDA Humanoid Robot,
(B) Painted with Retro-reflective Material,
(C) Example of Projecting a Human onto it,
(D) Another Example (adopted from [13]).

## 3. Mutual Telexistence using TWISTER: Telexistence Wide-angle Immersive STEReoscope

Another approach to mutual telexistence without the use of robotics can be taken if we restrict our purposes only to communication. The basic idea [18] is shown in Figure 9. Each human user stands inside of a booth with a rotating cylindrical mechanism that plays the role of both a display device and an input camera device to capture moving pictures of the user inside the booth. Each user can see the three dimensional figures of other users working in real-time in the mutual virtual environment.

This concept was first proposed in 1996, and a preliminary experiment successfully demonstrated the feasibility of the idea [18].

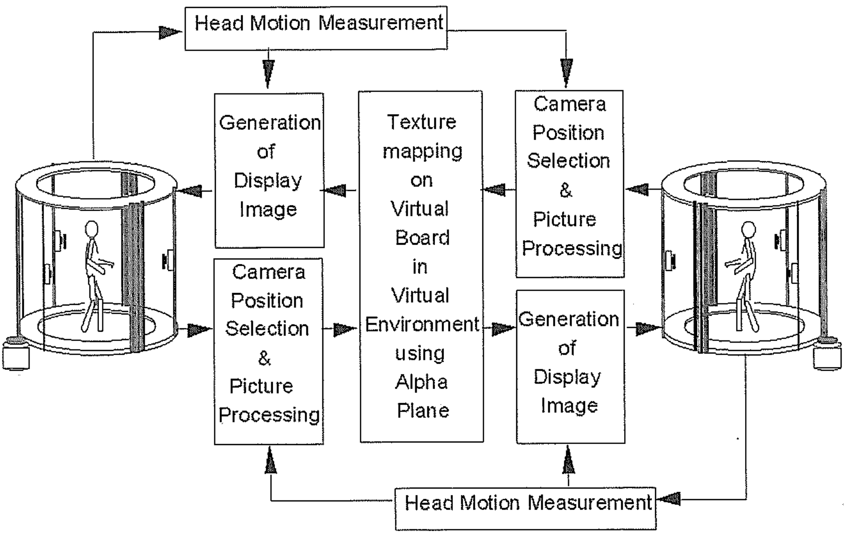


**Figure 9:** Basic Idea of Mutual Telexistence Booth (Adpoted from [18]).

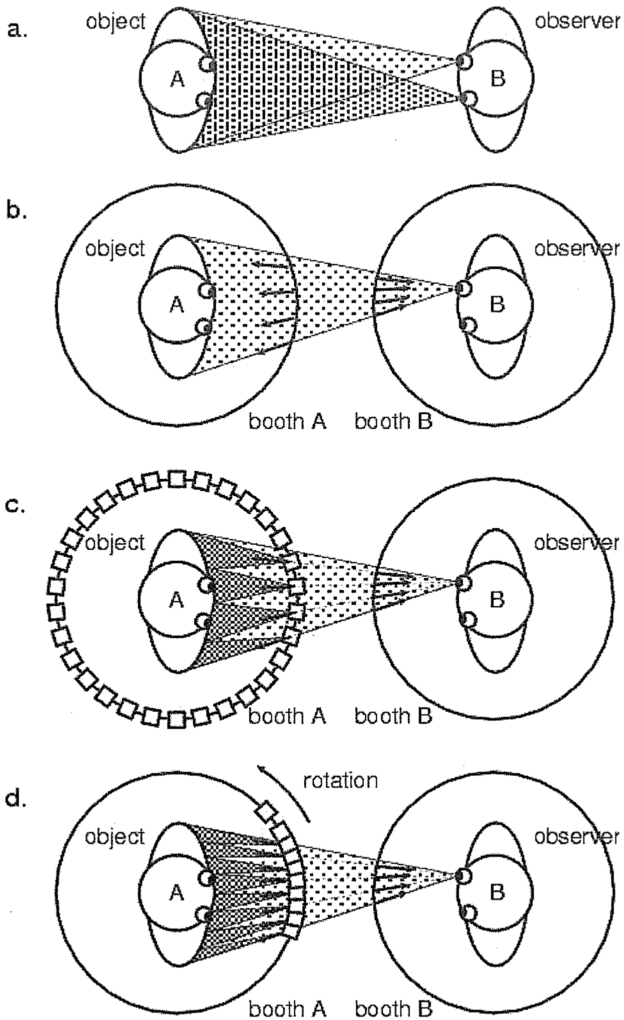


**Figure 10:** Principle of Capture and Display.
(a) supposed situation, (b) ray group seen by the observer, (c) ray group captured by cameras,(d) selection of appropriate rays from those captured by the rotating cameras (adopted from [21]).

Figure 10 shows the principle of the method. To synthesize the situation in Figure 10(a), cameras in booth A capture the light rays as seen from the supposed direction of the observer. These rays are transmitted and displayed on the cylindrical display of booth B (Figure 10(b)).

In general, in order to display three-dimensional objects for an arbitrary viewpoint outside a closed surface, ray information is required from a sufficient variation of directions inward, and at points of sufficient density over a closed surface separating the observer and the object. However, it is difficult to capture images from continuous viewpoints simultaneously because each camera occupies physical space. To increase the number of viewpoints, we considered two approaches: to reduce the camera size (c), and to exploit the camera's motion (d).

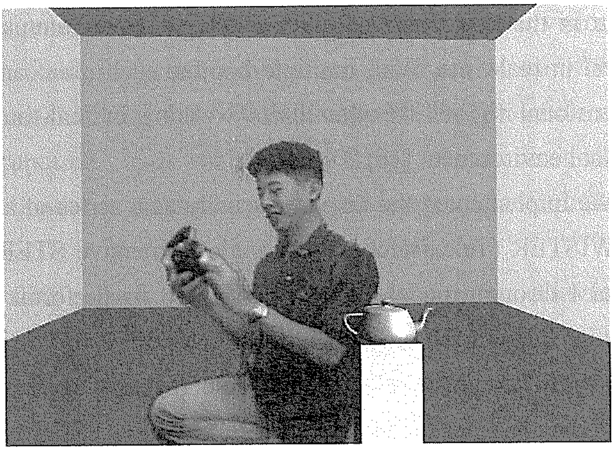

**Figure 11:** Constructed Human Figure. Images from an arbitrary viewpoint are constructed using rays captured by a camera array and placed in a virtual environment (adopted from [20]).

Figure 11 shows an example of capturing a human figure in real-time and displaying it in a virtual environment [19]. First, with a virtual viewpoint given by a user, the rendering PC calculates the regions of each camera image used for multi-texture-mapping. Next, the information of the region is sent to the control PC and used as an indication of the video switch. The switch timing is synchronized with the camera scanning, and the camera scanning direction is vertical. In this way, the rendering PC can selectively capture the necessary column image from the cameras.

Then, the captured images are texture-mapped onto a plane at an corresponding focal distance in the virtual three-dimensional space. This process is equivalent to the simple memory copy mentioned previously. Finally, the rendering PC renders the scene with 3D graphics. One cycle of all these processes completes within video rate (1/30[sec]), so the system realizes real-time rendering.

As described earlier, the basic idea of this form of mutual telexistence is the projection of human beings into a mutual virtual environment in real-time. With multiple booths, each user can see the three dimensional figures of other users working in real-time in the mutual virtual environment [18, 20].

We implemented the display partially as a series of apparatus dubbed TWISTER (Telexistence Wide-angle Immersive STERoscope) from model I through model III, and confirmed its performance as a stereoscopic display of full-color images [21].

TWISTER has a rotating display and camera units surrounding the observer. One unit consists of two LED (Light-Emitting Diode) arrays, a parallax barrier, and a camera. Each LED array consists of pairs of red, green, and blue LEDs, and displays time-varying patterns so that the observer can perceive an image. Due to the use of LEDs, TWISTER can be used as a display of high intensity full-color images, even in a bright room.

The rotation of the display unit makes it a wide angle display. In fact, the angle of view as a normal display is 360 degrees. In addition, since the horizontal and temporal resolutions of this display are determined by the period of LED emission, the spatio-temporal resolution can be adaptive and optimized to the subject.

The key device for autostereopsis is the parallax barriers. One of the LED arrays is for the left eye, and the other is for the right eye. Because the parallax barrier obscures LED emission from the opposite side, different images are shown to the left and right eyes. The angle of view as a stereoscopic display depends on the direction and the position of the observer. If the head of the observer is fixed, it exceeds 120 degrees in an ideal condition. On the other hand, if the observer always faces the center of the image region of interest, it can be 360 degrees.

With the moving parallax barriers, the crosstalk between the left eye image and the right eye image is reduced to almost zero, which gives it a powerful advantage over other stereoscopic vision systems. Since the rotating unit has cameras on it, you can capture the image of the observer simultaneously. With this system, the face of the observer is clearly captured, and natural non-verbal communication between multiple booths is achieved when the image data is transferred in real-time.

The rotator of TWISTER rotates counterclockwise (viewed from the top) at a constant speed of about one revolution per second. The sync signal is generated when a photo detector attached to the rotator senses the light from a photo diode attached to the framework.

Display units are attached at a distance of 800 millimeters from the center. Under that condition, with convergence, the observer is able to fuse an image of an object at a distance from 0.18 to 8 meters, which complies with the purpose of face-to-face telecommunication.

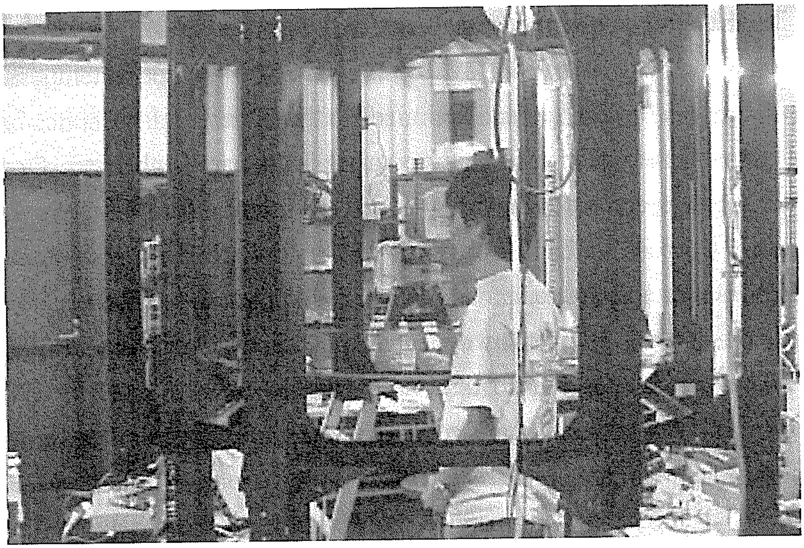

**Figure 12:** General View of TWISTER II (2001).

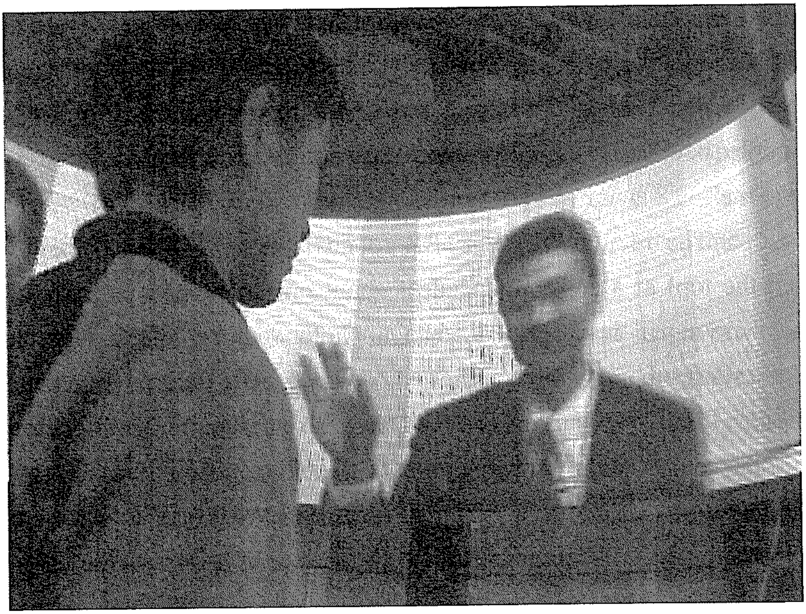

**Figure 13:** Preliminary Experimental Telexistence Communication using TWISTER II (2001).

To date, we have achieved full-color presentation of images. With LEDs, it can easily be seen in a well-lit room. The capabilities for autostereopsis without eyewear, and panoramic (360degree) presentation of normal two dimensional images have been also confirmed (Figure 13).

## 4. Conclusion

According to the American Heritage Dictionary, "virtual" means, "existing in essence or effect though not in actual fact or form." Thus virtual reality must have the essence of the reality in its computer-generated environment or a transmitted remote environment so that it effectively becomes the reality itself. Telexistence is the concept of overcoming limita- tions of time and space by presenting a sensation of existence in a virtual sense. It is regarded as the technology that enables humans to be virtually ubiquitous, i.e., being or seeming to be everywhere at the same time.

One of the most promising technologies today is the integration of virtual reality and robotics on the network. It is called networked robotics in general and R-Cubed (Real-time Remote Robotics) in particular. R-Cubed is a Japanese national R&D scheme toward practical applications of telexistence through various kinds of networks, including next generation Internets. The Japanese Ministry of Economy, Trade and Industry (METI) initiated a 5-year "Humanoid Robotics Project (HRP)" in April 1998, which ended in March 2003. In the project, telexistence in a bipedal humanoid robot using a newly developed telexistence cockpit was realized, and its feasibility was successfully demonstrated.

Mutual telexistence is one of the most important technologies for the realization of networked telexistence, because users "telexisting" in a robot must know whom they are working with over the network. A method using a HMP (Head Mounted Projector) and a robot with retro-reflective covering was proposed and proved to be a promising approach toward the realization of mutual telexistence using robots.

Technology based on the concept of networked telexistence enables users to meet and talk as if they share the same space and time, even if they are far apart from each other. This is the goal of the development of mutual telexistence communication systems, as a natural progression from the telephone to the telexistence-videophone. TWISTER (Telexistence Wideangle Immersive STERoscope) was devel- oped and its efficacy was demonstrated and proved. It will be widely used as a telexistence booth for communication and control with a sensation of presence.

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