Telexistence and Retro-reflective Projection Technology (RPT)

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Abstract. This paper reviews how the original telexistence (tele-existence) technology has been developed, and describes a newly developed method of mutual telexistence using projection technology onto retro-reflective objects dubbed RPT (Retro-reflective Projection Technology). Telexistence is fundamentally a concept named for the general technology that enables a human being to have a real-time sensation of being at a place other than where he or she actually exists, and being able to interact with the remote environment, which may be real, virtual, or a combination of both.   It also refers to an advanced type of teleoperation system that enables an operator at the control to perform remote tasks dexterously with the feeling of existing in a surrogate robot working in a remote environment.   Telexistence in the real environment through a virtual environment is also possible.   Although conventional telexistence systems provide an operator the real-time sensation of being in a remote environment, persons in the remote environment have only a feeling that a surrogate robot is presented, not the operator.   Mutual telexistence aims to solve this problem so that the existence of the operator is apparent to persons in the remote environment by providing mutual sensations of presence.   This has become possible by the use of RPT.

1. Introduction

Telexistence (tele-existence) is a technology that enables us to control remote objects and communicate with others in a 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 became 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, we 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 humans to use a humanoid robot in the remote environment as if it was an other self, i.e. they are able to have the sensation of being 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 a method of mutual telexistence based on the projection of real-time images of the operator on the surrogate robot, based on RPT (Retro-reflective Projection Technology).

2.   Short History of Telexistence

Figure 1 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].
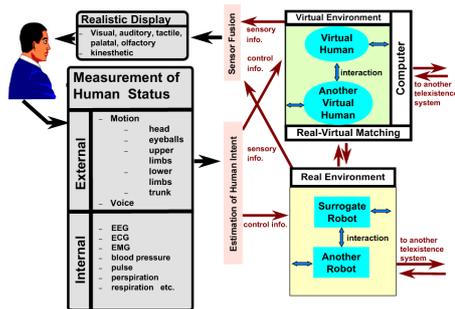
Fig.1 Concept of Telexistence.

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].
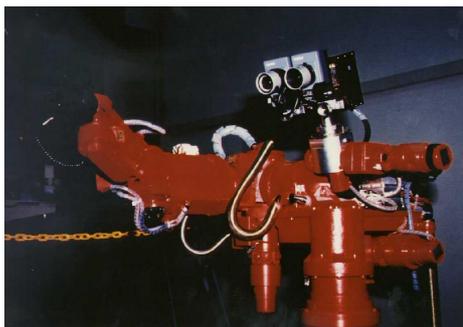
Fig. 2 Telexistence Surrogate Anthropomorphic Robot (TELESAR) at Work (1988).

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 [6,7].

The slave robot has an impedance control mechanism for contact tasks and to compensate for errors that remain even after calibration. An experimental operation in a poor visibility environment was successfully conducted by using a humanoid robot called TELESAR (TELExistence Surrogate Anthropomorphic Robot) (Fig.2) and its virtual dual. 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.

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

A networked telexistence paradigm called R-cubed (Real-time Remote Robotics) was proposed in 1986, and several research efforts towards the goal are being conducted, including a real-time remote robot manipulation language dubbed RCML [6,7].

Fig. 3 Virtual TELESAR at Work (1993).

Fig. 4 Telexistence Master (1989).

Telexistence technology was adapted in METI (Ministry of Economy, Trade and Industry)'s national five year HRP (Humanoid Robotics Project: 1998-2003) for a new type of cockpit system to control a humanoid bipedal robot, as shown in Figure 5. The telexistence cockpit was completed for this project in March 2000 (Fig.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].

Fig.6 Telexistence Cockpit for Humanoid Control (2000).
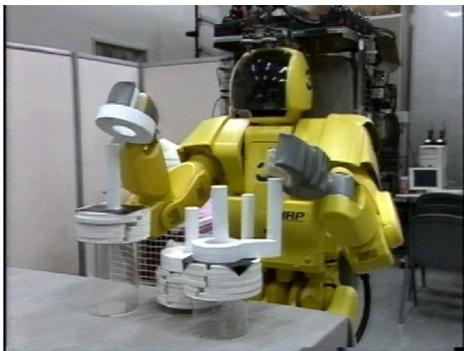
Fig.5 HRP Humanoid Robot at Work (2000).

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. As the robot walked around, real images captured by a wide field of view multi-camera system were displayed on four screens of the surrounded visual display. This made the operator feel as if he or she was 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 sensors on the real robot. The model 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 was his or her other self. Persons can control the robot by just moving their body naturally, without using verbal commands. The robot conforms to the person's motion, 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 observers 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 the use of projection technology with retro-reflective material as a surface, which we call RPT (Retro-reflective Projection Technology).

3. Retro-reflective Projection Technology (RPT)

A Head Mounted Display (HMD) and a CAVE (CAVE Automatic Virtual Environment) are two classic virtual reality visual displays. Although they are quite useful displays, it is also true that they have some shortcomings. The former has a tradeoff of high resolution and wide field of view, and the latter has problems concerning the user's body casting shadows on a virtual environment, and the interaction between the user's real body and the virtual interface. In addition, both displays have problems concerning occlusion when in use under the augmented reality condition, i.e. virtual objects and real objects are mixed. The problems of conventional displays HMD and CAVE are shown in Figure 7 (C) and (D), respectively.

Figure 7 (A) shows a virtual vase and a virtual ashtray on a virtual desk. When a real hand is placed between two virtual objects, an ideal occlusion should be depicted as in Figure 7 (B), i.e., the real hand occludes the virtual vase and is occluded by the virtual ashtray. However, a real hand cannot occlude the virtual vase nor be occluded by the virtual ashtray when an optical see-through HMD is used to display virtual objects, and the hand and the ashtray look as if they are transparent. This is simply due to the fact that the physical display position is always just in front of the eyes of the user when HMD is used.
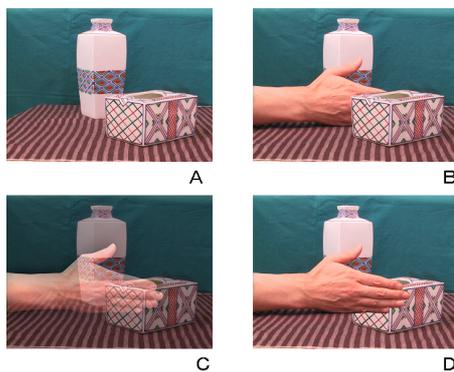
On the other hand, the virtual ashtray cannot occlude a real hand when IPT (Immersive Projection Technology) like CAVE is used, as shown in Figure 7 (D). This is due to the fact that the display position of virtual objects is always at the screen surface, which is one to two meters away from the human user when CAVE and other IPT (Immersive Projection Technology) displays are used.

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 projection surface. We call this type of display technology RPT (Retro-reflective Projection Technology).

Under the RPT configuration, a projector is arranged at the axial symmetric position of a user's eye with reference to a half-mirror, with a pinhole placed in front of the projector to ensure adequate depth of focus, as shown in Figure 8. Images are projected onto a screen that is either made, painted, or covered with retro-reflective material [17].
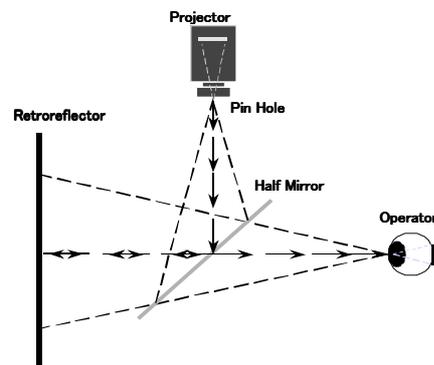
Fig.8 The Principle of RPT system.

A retro-reflective surface projects back the projected light just to the direction of projection, while conventional screens normally used for IPT scatter projected lights in all directions ideally as a Lambertian surface (Fig.9). Figure 10 shows how a retro-reflective surface behaves. It is covered with microscopic beads of about 50 micrometers in diameter, which reflect back the incident light to the incident direction. It can also be realized with a microstructure of prism-shaped retro-reflectors densely placed on a surface.

Fig. 7 (A) A virtual vase and a virtual ashtray on a virtual desk; (B) An ideal occlusion when a real hand is placed between two virtual objects; (C) Unfavorable results when optical see-through HMD is used; (D) Unfavorable results when IPT (Immersive Projection Technology) like CAVE is used.

Fig. 9 Three typical reflections.

specular reflection   diffused reflection   retro-reflection
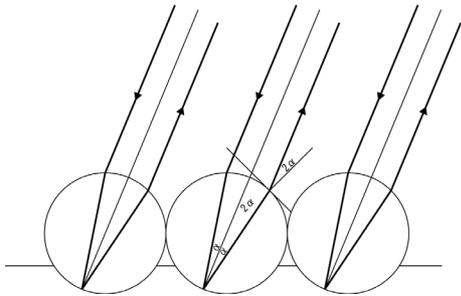
Fig. 10   Retro-reflective surface densely covered with microscopic beads with about 50 micrometer diameter. Ideally, refractive index should be 2.

The retro-reflector screen, together with the pinhole, ensures that the user always sees images with accurate occlusion relations.   In the construction of an RPT system, 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 an RPT system, 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 as shown in Figure 11. Figure 12 shows a general view of a prototype HMP.
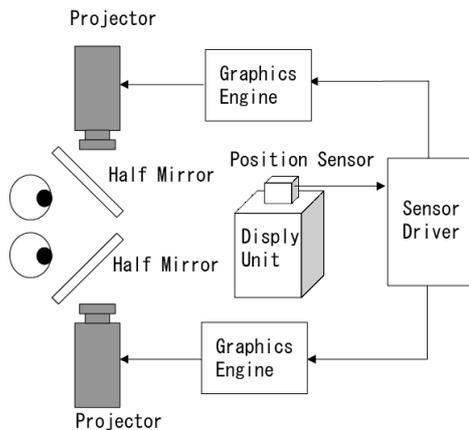
Fig.11 Principle of stereo display using RPT with Head Mounted Projector (HMP).

Fig. 12 Head Mounted Projector (HMP) with RPT.

Figure 13 shows an example of an image projected on a sphere painted with retro-reflective material. Figure 14 shows an example of projecting a virtual cylinder onto a Shape Approximation Device (SAD) [18], which is a haptic device that enables the user to touch geometrical shapes as if they were real.   The use of the SAD as the retro-reflective screen enables us to feel just as we see by using a HMP.

Fig.13 Projected image on a spherical retro-reflective screen.

In the figure, (A) illustrates the principle of SAD, (B) shows an image to be displayed, (C) is an actual SAD, and (D) indicates the image projected onto SAD, which can be touched as it is seen.
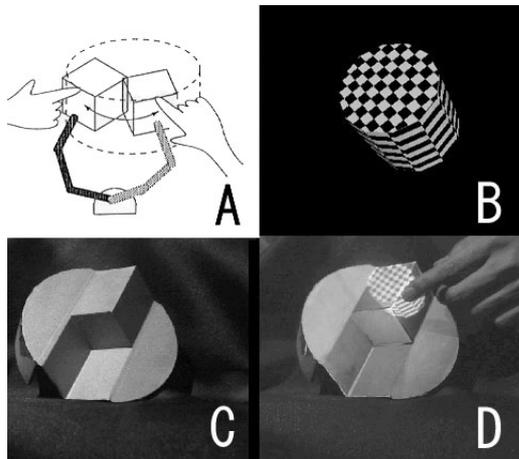
Fig.14 Projected image on a Surface Approximation Device (SAD).
A: Principle of SAD; B: Image; C: Actual SAD; D: Image
projected on SAD, which can be touched as it is seen.

Figure 15 shows an example of the use of RPT for augmented reality. Pre-captured x-ray and/or MRI data can be superimposed onto a human patient so that a surgeon can have open surgery related information even under the minimally invasive surgery environment. By superimposing ultra-sonic data, real-time presentation of inner body information is also possible through RPT.

Fig.15 An Augmented Reality Application using PRT.

Figure 16 shows another example of applying RPT to medicine.
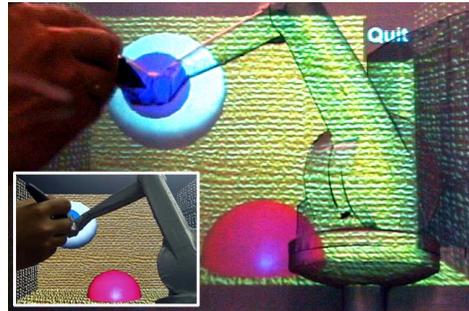
Fig. 16 Another Example of the application of RPT to medicine.

Figures 17 and 18 show application examples of using RPT for optical camouflage. In Fig. 17, pre-captured a background image is projected so that a retro-reflective object grasped by a human appears to be transparent.

Fig. 17 An optical Camouflage Application using RPT.

Figure 18 shows how optical camouflage can be achieved using real-time video information. Figure 19 shows how RPT is applied to realize the situation of Figure 18. The coat is made of retro-reflective material so that the coming light is reflected back to the same direction that it comes from. Microscopic beads on the surface of the coat have the function of retro-reflection.

A half mirror makes it possible for a spectator to see virtually from the position of the projector. An HMP projects an image of the background scenery captured by the video camera behind the camouflaged subject. A computer calculates the appropriate perspective and transforms the captured image to the image to be projected on the subject using image-based rendering techniques. Since the cloak the subject is wearing is made of a special retro-reflective material, which reflects back the incident light just the same direction it comes from,

an observer looking through a half mirror sees a very bright image of the scenery so that he is virtually transparent.

Fig. 18 Another example of application of RPT to optical camouflage.
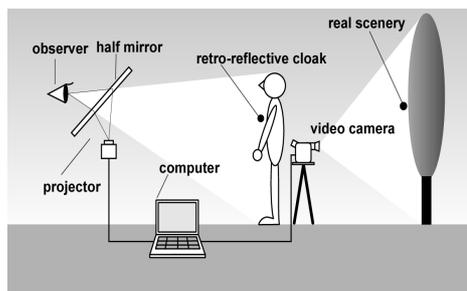
Fig. 19 A schematic diagram of the RPT system used for the optical camouflage in Fig.18.

4. Mutual Telexistence using RPT

More than twenty years have passed since we initially proposed the 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 at once. 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.

By using RPT, the problem can be solved as shown in Figure 19 [13]: 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′*, and 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.
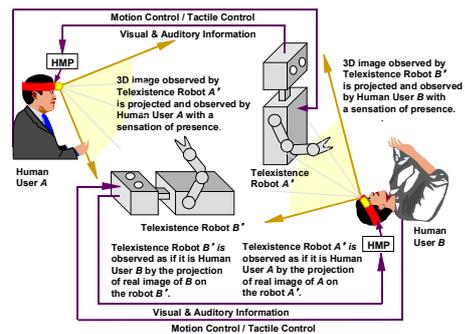
Fig. 20 Concept of Robotic Mutual Telexistence (adopted from [13]).
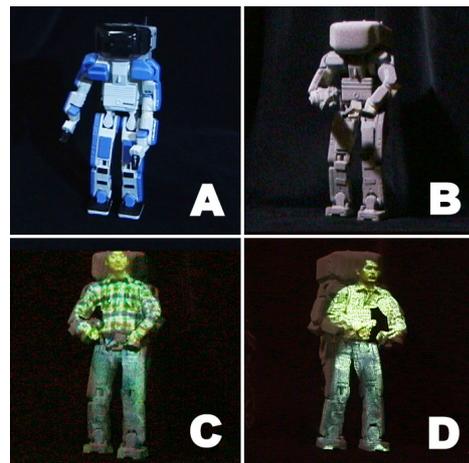
Fig. 21 (A) Miniature of the HONDA Humanoid Robot,
(B) Painted with Retro-reflective Material,
(C) Example of Projecting a Human onto it,
(D) Another Example (adopted from [13]).

Figure 21 presents an example of how mutual telexistence can be achieved through the use of RPT. Figure 20(A) shows a miniature of the HONDA Humanoid Robot, while Figure 21(B) shows the robot painted with retro-reflective material. Figures 21 (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.

5. Conclusions

Projection technology on Retro-reflective surfaces is called RPT (Retro-reflective Projection technology), which is a new approach to augmented reality (AR). The first demonstration of RPT was made at SIGGRAPH98, followed by demonstrations at SIGGRAPH99 and SIGGRAPH2000. In this keynote paper, the principle of RPT is explained, and applications to AR are discussed.

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 RPT, especially an 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.

References

[1] S.Tachi, K.Tanie, K.Komoriya and M.Kaneko: Tele-existence (I): Design and evaluation of a visual display with sensation of presence, Proceedings of the 5th Symposium on Theory and Practice of Robots and Manipulators (RoManSy '84), pp.245-254, Udine, Italy, (Published by Kogan Page London), June 1984.

[2] S.Tachi, H.Arai, I.Morimoto and G.Seet: Feasibility experiments on a mobile tele-existence system, The International Symposium and Exposition on Robots (19th ISIR), Sydney, Australia, November 1988.

[3] S.Tachi, H.Arai and T.Maeda: Development of an Anthropomorphic Tele-existence Slave Robot, Proceedings of the International Conference on Advanced Mechatronics (ICAM), pp.385-390, Tokyo, Japan, May 1989.

[4] S.Tachi, H.Arai and T.Maeda: Tele-existence master slave system for remote manipulation, IEEE International Workshop on Intelligent Robots and Systems (IROS'90), pp.343-348, 1990.

[5] S.Tachi and K.Yasuda: Evaluation Experiments of a Tele-existence Manipulation Sysytem, Presence, vol.3, no.1, pp.35-44, 1994.

[6] Y.Yanagida and S.Tachi: Virtual Reality System with Coherent Kinesthetic and Visual Sensation of Presence, Proceedings of the 1993 JSME International Conference on Advanced Mechatronics (ICAM), pp.98-103, Tokyo, Japan, August 1993.

[7] K.Oyama, N.Tsunemoto, S.Tachi and T.Inoue: Experimental study on remote manipulation using virtual reality, Presence, vol.2, no.2, pp.112-124, 1993.

[8] S.Tachi: Real-time Remote Robotics- Toward Networked Telexistence : IEEE Computer Graphics and Applications, vo.18, Nov-Dec98, pp.6-9, 1998.

[9] Y.Yanagida, N.Kawakami and S.Tachi: Development of R-Cubed Manipulation Language - Accessing real worlds over the network, Proceedings of the 7th International Conference on Artificial Reality and Tele-Existence (ICAT'97), pp.159-164, Tokyo, Japan, December 1997.

[10] T.Nishiyama, H.Hoshino, K.Suzuki, R.Nakajima, K.Sawada and S.Tachi, "Development of Surrounded Audio-Visual Display System for Humanoid Robot Control", Proc.of 9th International Conference of Artificial Reality and Tele-existence (ICAT'99), pp. 60-67, Tokyo, Japan, December 1999.

[11] T.Nishiyama, H.Hoshino, K.Suzuki, K.Sawada and S.Tachi, "Development of Visual User Interface Embedded in Tele-existence Cockpit for Humanoid Robot Control", Proc. of IMEKO 2000 World Congress, Vol.XI (TC-17 & ISMCR2000), pp.171-176, Vienna, Austria, September 2000.

[12] S.Tachi, K.Komoriya, K.Sawada, T.Nishiyama, T.Itoko, M.Kobayashi and K.Inoue: Development of Telexistence Cockpit for Humanoid Robot Control, Proceedings of 32nd International Symposium on Robotics (ISR2001), pp.1483-1488, Seoul, Korea, April 2001.

[13] S.Tachi: Augmented Telexistence, Mixed Reality, pp.251-260, Published by Springer-Verlag, 1999.

[14] S.Tachi: Toward Next Generation Telexistence, Proceedings of IMEKO-XV World Congress, vol.X (TC-17 & ISMCR'99), pp.173-178 , Tokyo/Osaka, Japan, June 1999.

[15] S.Tachi: Toward the Telexistence Next Generation, Proceedings of the 11th International Conference on

Artificial Reality and Tele-Existence, (ICAT2001), pp.1-8, Tokyo, Japan, December 2001.

[16] N.Kawakami, M.Inami, T.Maeda and S.Tachi: Media X'tal -Projecting virtual environments on ubiquitous object-oriented retro-reflective screens in the real environment-, SIGGRAPH'98, Orlando, FL, July 1998.

[17] M.Inami, N.Kawakami, D.Sekiguchi, Y.Yanagida, T.Maeda and S.Tachi: Visuo-Haptic Display using Head-Mounted Projector, Proceedings of IEEE Virtual Reality 2000, pp. 233-240, New Brunswick, NJ, March 2000.

[18] S.Tachi, S.Tachi, T.Maeda, R.Hirata and H.Hoshino: A construction method of virtual haptic space, Proceeding of the 4th International Conference on Artificail Reality and Tele-Existence (ICAT'94), pp.131-138, Tokyo, Japan, July 1994.

[19] M. Inami, N. Kawakami, Y. Yanagida, T. Maeda and S. Tachi, Method of and Apparatus for Displaying an Image, US PAT. 6,283,598 2001.

[20] M. Inami, N. Kawakami, Y. Yanagida, T. Maeda and S. Tachi, Method and Device for Providing Information, US PAT. 6,341,869 2002.

[21] S.Tachi: Two Ways of Mutual Communication: TELESAR and TWISTER, in S.Tachi ed. Telecommunication, Teleimmersion and Telexistence, IOS Press, ISBN 1-58603-338-7, pp. 3-24, 2003.