Proceedings of the ICAT'94 (4th International Conference on Artificial Reality and Tele-Existence)
Tokyo, Japan, July 14-15, 1994

A CONSTRUCTION METHOD OF VIRTUAL HAPTIC SPACE

Susumu Tachi, Taro Maeda, Ryokichi Hirata and Hiroshi Hoshino

RCAST, The University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153 Japan
+81-3-3481-4467 (phone)
+81-3-3481-4469 (fax)
tachi@tansei.cc.u-tokyo.ac.jp (e-mail)

Key Words: tele-existence, telepresence, teleoperation, haptic display, virtual reality

Abstract

A method is proposed to construct a virtual haptic space driven by the same environment model of the real world as of the visual space. Human limb motion is measured in real time and the subspace of the total haptic space, which is or will be in contact with the human end effector, is constructed using the haptic space display device. Its end effector is an environment shape approximation device whose shape is specially designed to approximate several shapes by changing its sides of contact. Its position and orientation is controlled by a pantographic mechanism called an active environment display. The shape of the haptic space is approximated by the environment shape approximation device, and inertia, viscosity and stiffness of the haptic space are generated by the use of the mechanical impedance controlled active environment display.

1.Introduction

Haptic space plays an important role in virtual representation of the computer synthesized world or the robot transmitted world of the remote environment, such as tele-existence. Tele-existence aims at a natural and efficient remote control of robots by providing the operator with a real time sensation of presence. It is an advanced type of teleoperation system which enables a human operator at the controls to perform remote manipulation tasks dexterously with the feeling that he or she exists in one of the remote anthropomorphic robots in the remote environment, e.g., in a hostile environment such as those of nuclear radiation, high temperature, and deep space. The authors have been working on the research for the improvement of the teleoperation by feeding back rich sensory information which the remote robot has acquired to the operator with a sensation of presence, the concept which was born independently both in Japan and in the United States. It is dubbed tele-existence in Japan and telepresence or virtual reality in the United States [1-18].

In our first reports [3,8], the principle of the tele-existence sensory display was proposed. Its design procedure was explicitly defined. Experimental visual display hardware was built, and the feasibility of the visual display with the sensation of presence was demonstrated by psychophysical experiments using the test hardware. A method was also proposed to develop a mobile tele-existence system, which can be remotely driven with the auditory and visual sensation of presence. A prototype mobile tele-vehicle system was constructed and the feasibility of the method was evaluated [13]. In order to study the use of the tele-existence system in the artificially constructed environment, the visual tele-existence simulator was designed, a quasi-real-time binocular solid model robot simulator was made, and its feasibility was experimentally evaluated [14].

In the recent papers [15,16], the first prototype tele-existence master slave system for remote manipulation experiments was designed and developed, and a preliminary evaluation experiment of tele-existence was conducted. An experimental tele-existence system in real and/or virtual environment was designed and developed, and by conducting an experiment comparing a tele-existence master slave system with a conventional master slave system, efficacy of the tele-existence master slave system and the superiority of the tele-existence method was demonstrated experimentally [17,18]. Quantitative evaluation of the tele-existence manipulation system was conducted through tracking tasks by using a tele-existence master slave system designed and developed [19].

In this paper, a construction method of virtual haptic space is proposed, a test hardware has been constructed, and the feasibility study has been conducted using the hardware.

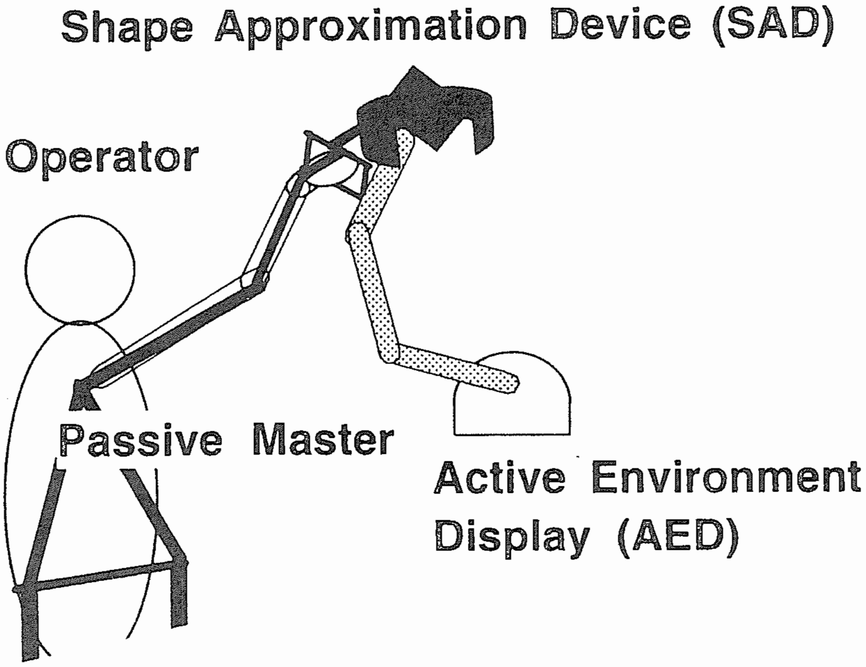


Fig.1 Conceptual Diagram of the Virtual Haptic Space Construction Method.

2.Virtual Haptic Space

Several efforts have been made for the construction of the virtual haptic space [20, 21]. Most of the developed displays were fundamentally force/torque displays and very few were shape displays. Hirota and Hirose [21] succeeded to construct a shape display of the object with continuous surfaces. However, it could not represent the objects with edges and vertices. In this paper, a method is proposed to represent haptic space with edges, vertices and surfaces with mechanical impedance information, and experimental hardware is constructed to demonstrate the feasibility of the method.

2.1 Representation of the Virtual Haptic Space

We restrict our consideration to the case that we could touch the virtual haptic space at one point, i.e. at the finger tip. We also restrict ourselves to the condition that we abandon the representation of the texture of the surface. Then the shape of an object in the virtual haptic space can be represented as a function of three dimensional point of contact (x, y, z) in the world Cartesian coordinate. One of the attributes of the virtual haptic object is which type of the fundamental shape elements the point of contact belongs to, e.g., surface, edge or vertex together with the normal vector of the surface at the point if it belongs to a surface, or the direction vector of the edge if it belongs to an edge. The virtual object's attribute which we consider other than its shape is its mechanical impedance, i.e., inertia, viscosity and stiffness for three transnational directions and three rotational directions.

Figure 1 shows how an object in the real environment is presented in the virtual haptic space. Human upper limb motion is measured by a passive master arm and the tip position and orientation of the human finger is calculated. The measured position is sent to the computer, which calculate the nearest object in the virtual haptic space. The information of the object, i.e., mechanical impedance, tangential surface and/or edge/vertex data is represented by the device which is consisted of a 6 degree of freedom impedance controlled active environment display (AED) and a shape approximation device (SAD).

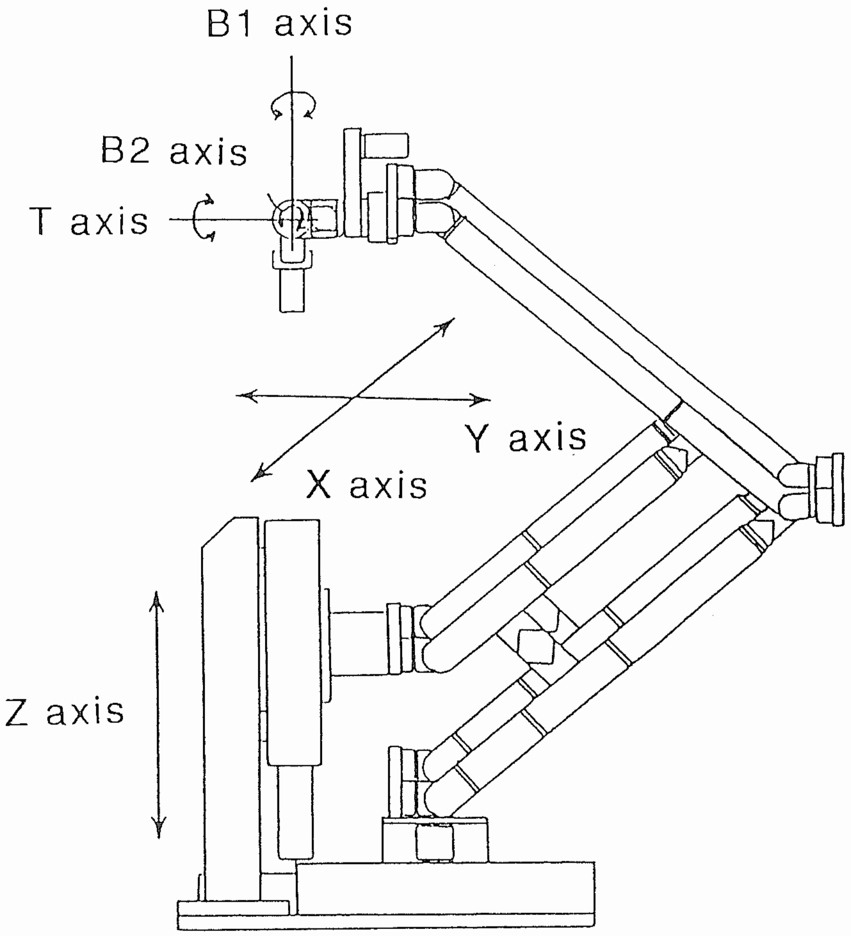


Fig.2 Active Environment Display (AED).

When the finger is in free space, no contact is made with the SAD. However, the SAD continues to display the appropriate shape information at the point nearest to the operator's finger tip. The AED follows is controlled to locate the SAD at the appropriate position based on the measurement of the finger position/posture and the model of the virtual haptic space. When the finger tip contacts the point on the virtual object, the human finger tip contacts the SAD with appropriate mechanical impedance given by the AED. When he/she moves his/her finger, he/she feels the shape of the contact point, whether it is an edge, a vertex or a part of the surface presented using the appropriate part of the SAD. If it is an edge, he/she can find which direction the line is in the virtual haptic space. When it is a surface, surface orientation is represented.

2.2 Active Environment Display (AED)

Figure 2 shows the active environment display designed. It has pantographic link mechanism with link ratio of 1:3. The displacements of x, y are magnified 3 times, and the displacement of z direction is magnified by 4. Auxiliary links are used to make the orientation of the end point of the mechanism independent of the position of the endpoint. This reduces the burden of the calculation for the control.

The range of the display is ±300 mm for each of the x, y, and z directions. As for the rotational range, ±180° for yaw, ±90° for roll, and +90° ; −45° for pitch.

2.3 Shape Approximation Device (SAD)

Figure 3 shows the shape approximation device designed, and Fig. 4 and Fig 5 show how surfaces and edges are approximated using the device. Continuous surfaces are approximated by the tangential plane at the representation point. As the contact point moves, the tangential plane follows the point changing its orientation according to the predetermined information.

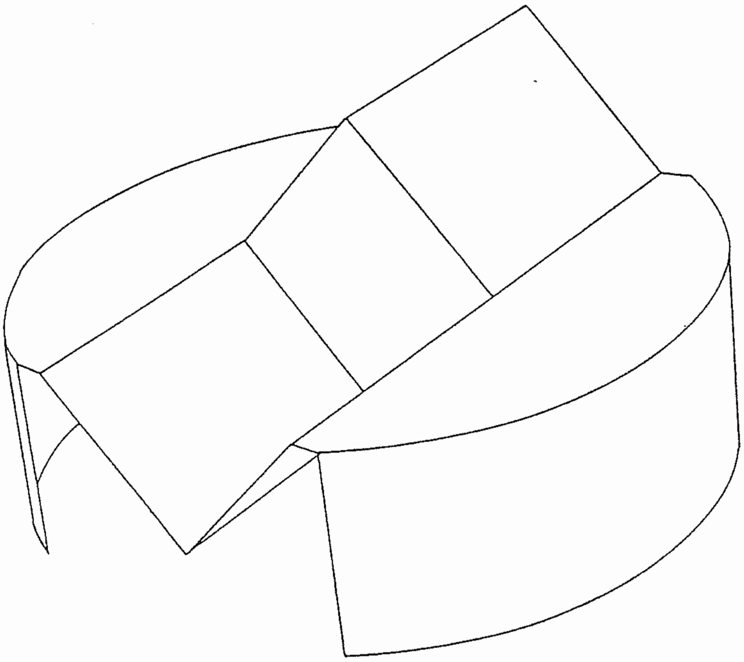


Fig.3 Shape Approximation Device (SAD).

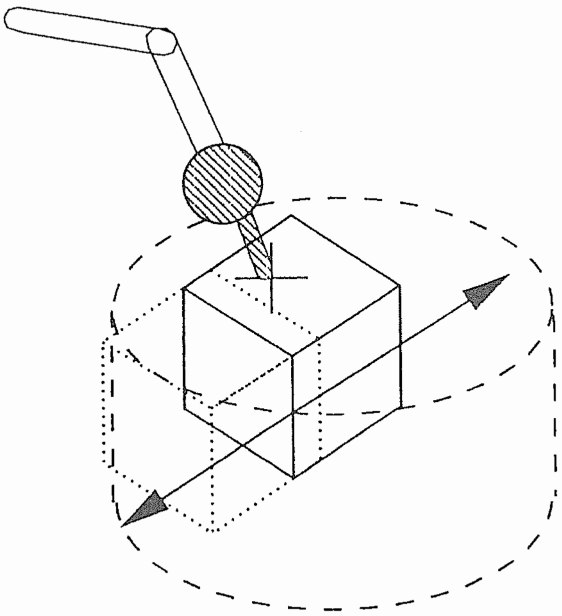


Fig.4 Surface Representation.

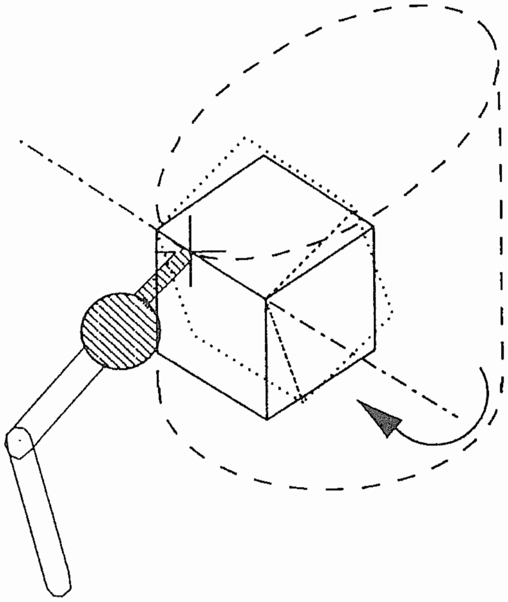


Fig.5 Edge Representation.

In order to approximate shapes in the environment, the approximation device must represent both convex edges and concave edges. The device has both convex edges and concave edges, and they are used to represent edged surfaces. By controlling the orientation and moving the device to the direction normal to the contact point surface normal, we can arrange any edge at the predetermined position with predetermined orientation. We can also turn the device around the edge presented to construct the predetermined contiguous surfaces.

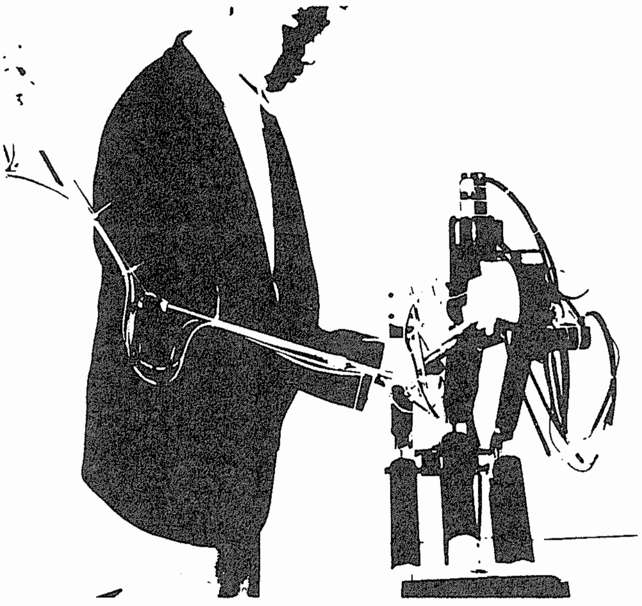
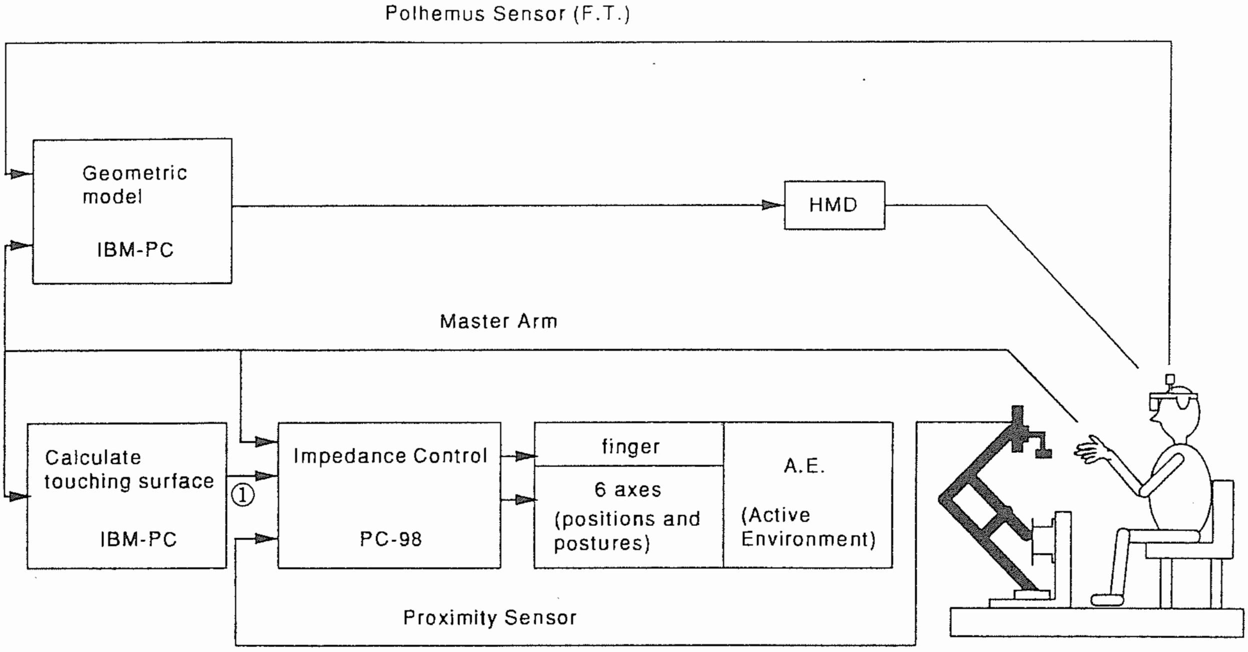


Fig.6 General View of the Experimental Hardware System Constructed.

3.Test Hardware

Figure 6 shows the experimental hardware system constructed, and Fig.7 indicates the block diagram of the system. Each object in the virtual space is represented in two ways. One is geometrical representation using polygons as is used in virtual visual space, and the other is represented using sphere, cylinder, cone, generalized cone, cube, parallelepiped, and combination of them. It is represented using the local coordinate fixed to the object in both cases. The position and orientation of the origin of the local coordinate is assigned relative to the world coordinate, and each point on the virtual model is calculated with reference to the world coordinate. Visual information and haptic information are driven by the same world model, and the visual rendering and haptic rendering are conducted in parallel. Nearest part of the virtual object to the finger is estimated by the method similar to the z–buffer method.



① · A predictive information (next motion)
· A touching point
· An information around touching surface
· An information of touching surface
(slope of surface, hardness of surface, a curved surface of a plane)

Fig.7 Block Diagram of Virtual Visual and Haptic Space Presentation System.

Figure 8 shows the passive master device with seven degrees of freedom to measure the position and orientation of a human user's finger tip position. The human finger is covered by the brace with ball point to ensure the point contact to the SAD. The brace also works to insulate human sensation from the movement of the SAD upon contact.

4.Conclusion

A method of constructing virtual haptic space was proposed, and an experimental hardware was made based on the proposed method. It was shown that an object shape with vertices, edges and surfaces could be represented. Concave edges as well as convex edges were successfully represented using the test hardware.

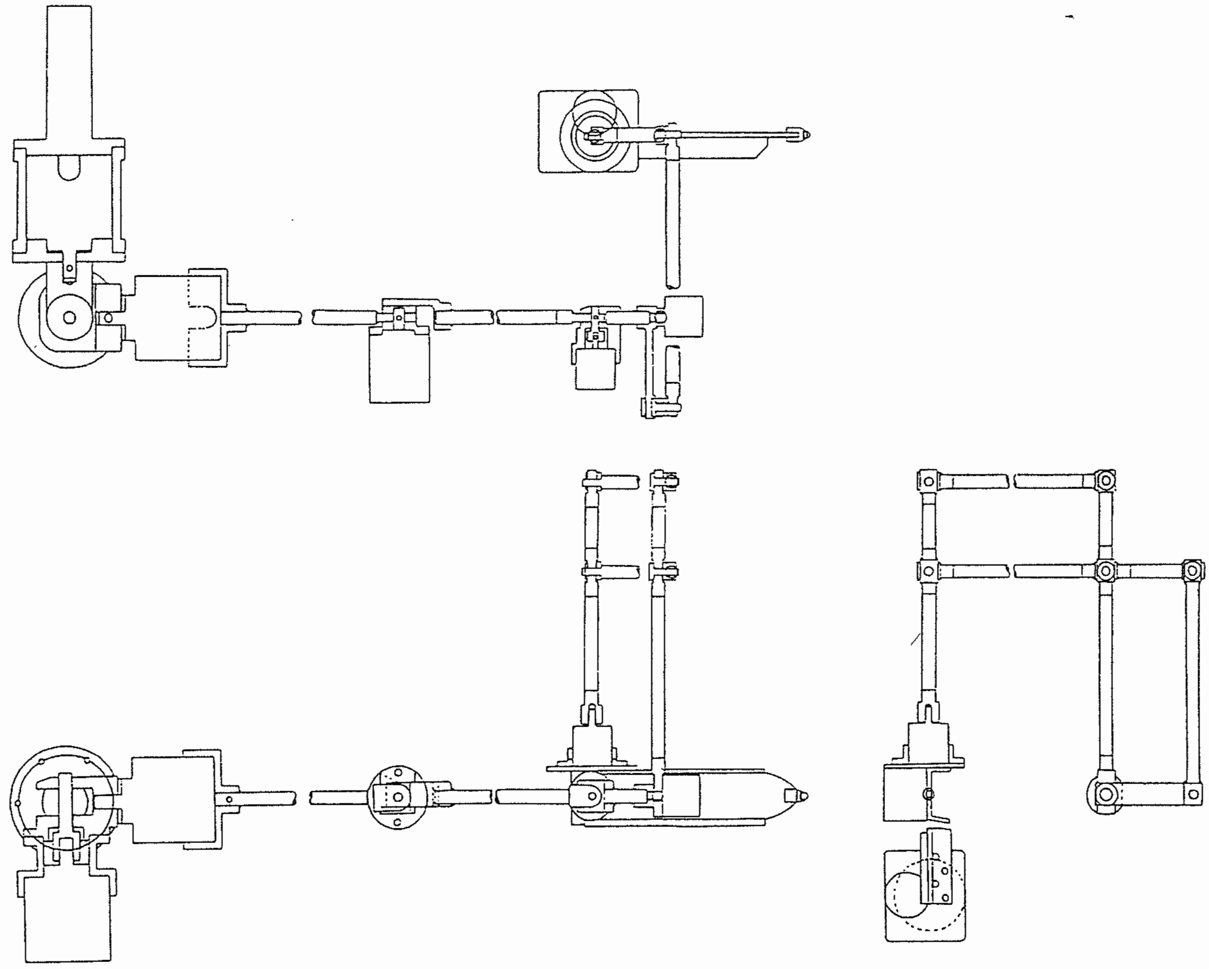


Fig.8 Passive Master System.

References

[1]Ivan E. Sutherland: A Head-Mounted Three Dimensional Display, Proceedings of the Fall Joint Computer Conference, pp. 757-764, 1968.

[2]Robert W. Mann: The Evaluation and Simulation of Mobility Aids for the Blind, American Foundation Blind research Bulletin, no.11, pp.93-98, 1965.

[3]S.Tachi and M.Abe: Study on Tele-Existence (I), Proceedings of the 21st Annual Conference of the Society of Instrument and Control Engineers (SICE), pp.167-168, 1982(in Japanese).

[4]D.L.Akin, M.L.Minsky et al.:Space Application of Automation: Robotics and Machine Intelligence Systems (ARAMIS)- Phase II, Telepresence Technology Base Development, NASA Contract Report 3734, 1983.

[5]S.Tachi, R.W.Mann and D.Rowell: Quantitative Comparison of Alternative Sensory Displays for Mobility Aids for the Blind, IEEE Transactions on Biomedical Engineering, vol.BME-30, no.9, pp.571-577,1983.

[6]R.L.Pepper, R.E.Cole and E.H.Spain: The Influence of Camera and Head Movement on Perceptual Performance under Direct and TV-Displayed Conditions, Proceedings of the SID, vol.24-1, pp.73-80, 1983.

[7]C.Schmandt: Spatial Input/Display Correspondence in a Stereoscopic Computer Graphic Work Station, Computer Graphics, vol.17-3, pp.253-261, July 1983.

[8]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.

[9]S.S.Fisher,M.Mcgreevy, J.Humphries and W.Robinett: Virtual Environment Display System, ACM 1986 Workshop on Interactive 3D Graphics, pp.1-11, Chapel Hill, North Carolina, USA, October 1986.

[10]F.P.Brooks: Walkthrough - a Dynamic Graphics Systems for Simulating Virtual Buildings, ACM 1986 Workshop on Interactive 3D Graphics, Chapel Hill, North Carolina, USA, October 1986.

[11]L.Stark et al.:Telerobotics: Display, Control and Communication Problems, IEEE Journal of Robotics and Automation, vol.RA-3-1, pp.67-75, February 1987.

[12]J.D.Hightower, E.H.Spain and R.W.Bowles: Telepresence: A Hybrid Approach to High Performance Robots, Proceedings of the International Conference on Advanced Robotics (ICAR '87), pp. 563-573, Versailles, France, October, 1987.

[13]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.

[14]S.Tachi, H.Arai and T.Maeda: Tele-existence simulator with artificial reality (1), -Design and evaluation of a binocular visual display using solid models -, Proceedings of the IEEE International Workshop on Intelligent Robots and Systems (IROS'88), pp.719-724, 1988.

[15]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.

[16]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.

[17]S.Tachi, H.Arai, T.Maeda, E.Oyama, N.Tsunemoto and Y.Inoue: Tele-existence Experimental System for Remote Operation with a Sensation of Presence, Proceedings of the International Symposium on advanced Robot Technology ('91 ISART), pp.451-458, Tokyo, Japan, March 1991.

[18]T.Maeda and S.Tachi: Development of Light-weight Binocular Head-mounted Displays, Proceedings of the Second International Symposium on Measurement and Control in Robotics (ISMCR'92), pp.281-288, Tsukuba Science City, Japan, November 1992.

[19] S.Tachi and K.Yasuda: Evaluation Experiments of Tele-Existence Manipulation System, Proceedings of the Third International Conference on Artificial Reality and Tele-Existence (ICAT'93), pp.17-26, Tokyo, Japan, June 1993.

[20] H.Iwata and H.Noma: Artificial Reality with Forcefeedback: Development of Desktop Virtual Space with Compact Master Manipulator, ACM Computer Graphics, vol.24, no.4, 1990.

[21] K.Hirota and M.Hirose: Development of Surface Display, Proceedings of the 1993 IEEE Annual Virtual Reality International Symposium (VRAIS), pp.256-262, Seattle, Washington, September 1993.