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Experimental Evaluation of Tele-Existence Manipulation System

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Abstract

Tele–existence manipulation system has been evaluated quantitatively by conducting a manipulation task of block building. Effects of various characteristics, e.g., binocular vision, motion stereo caused by head movement, and the effect of natural alignment of the head and the arm, are analyzed by comparing quantitatively the results under several operational conditions. The time elapsed for the completion of the task is used as the criterion for the comparison. The comparison result revealed the statically significant dominance of the binocular vision with natural alignment of the head and the arm.

1.Introduction

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 psycho–physical 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].

In this paper, quantitative evaluation of the tele–existence manipulation system is conducte by using a tele–existence master slave system designed and developed according to the concept of tele–existence.

2.Tele-Existence Master Slave System

Figure 1 shows a general view of the tele-existence master slave manipulation system experimentally constructed. The tele-existence master slave system consists of a master system with a visual and auditory sensation of presence, computer control system and an anthropomorphic slave robot mechanism with an arm having seven degrees of freedom, a gripper hand, and a locomotion mechanism.

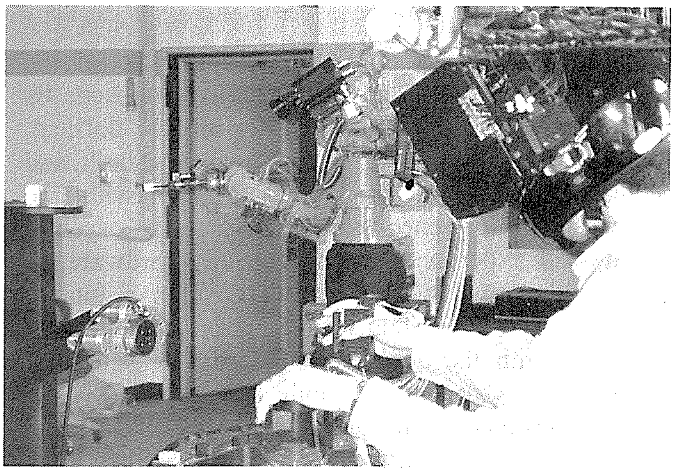

Fig.1 General View of the Tele-Existence Master Slave Manipulation System.

A human operator wears a 3D audio visual display with a sensation of presence. The audio visual display is carried by a link mechanism with six degrees of freedom. The link mechanism cancels all gravitational force through a counter balancing mechanism, which allows the operator's unconstrained movement in a relatively wide range of operation space. It also enables the display to follow the operator's head movement precisely enough to ensure his/her ordinary head movement. Maximum inertial force which is inevitably applied to the operator remains within 5 kgf. The master arm consists of ten degrees of freedom. Seven degrees of freedom are allocated for the arm itself, and an additional three are used to comply with the body movement (Fig.2).

The operator's head movement, right arm movement, right hand movement and other auxiliary motion including a joy stick operation and feet motion are measured by the master motion measurement system in real time without constraint. The measured head motion signal, arm motion signal, hand motion signal, and auxiliary signal are sent to the four computers, respectively. Each computer generates the command position of the slave head movement, the arm movement, hand movement or locomotion of the slave robot.

The servo controller controls the movement of the slave anthropomorphic robot. The slave robot has a locomotion mechanism and a hand mechanism. The robot has also a three degree of freedom neck mechanism on which a stereo camera is mounted. It has an arm with seven degrees of freedom, and a torso mechanism with one degree of freedom (waist twist). The dimensions and arrangement of the degree of freedom of the robot are designed to mimic those of the human being.

The motion range of each degree of freedom is set so that it will cover the movements of a human, while the speed is set to match the moderate speed of human motion (3 m/s at the wrist position). The weight of the robot is 60 kg, and the arm can carry a 1 kg load at the maximum speed of 3 m/s. The precision of position control of the wrist is ± 1 mm.A six axis force sensor installed at the wrist joint of the slave robot measures the force and torque exerted upon contact with an object, which is used to control the mechanical impedance of the robot's arm to the compliant pre-determined value.

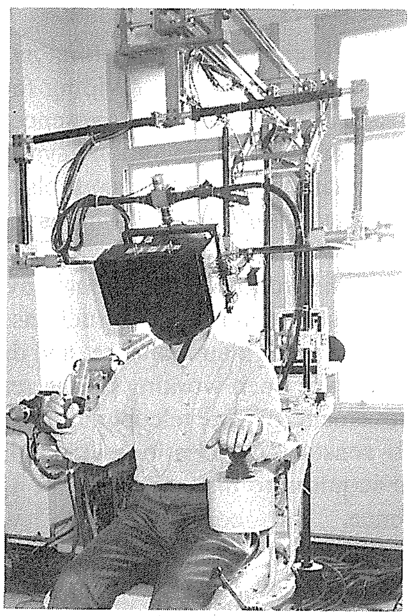

Fig.2 Tele-Existence Master System.

Figure 3 shows a general view of the anthropomorphic tele-existence slave robot under operation of building blocks.

A stereo visual and auditory input system mounted on the neck mechanism of the slave robot gathers visual and auditory information of the remote environment. These pieces of information are sent back to the master system, which are applied to the specially designed stereo display system to evoke sensation of presence of the operator. The measured pieces of information on the human movement are used to change the viewing angle, distance to the object, and condition between the object and the hand in real time. The operator observes the three dimensional virtual environment in front of his/her view, which changes according to his/her movement.

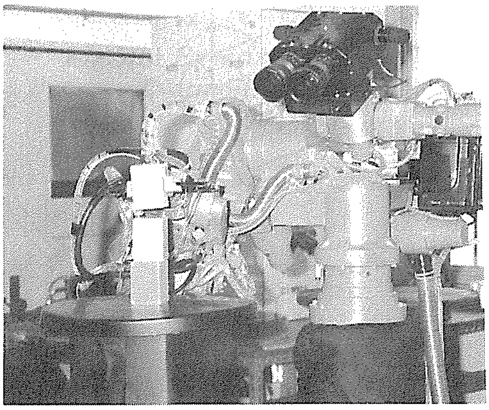

Fig.3 Tele-Existence Anthropomorphic Robot under Operation of Building Blocks.

The stereo visual display is designed according to the developed procedure which assures that the three dimensional view will maintain the same spatial relation as by direct observation [8,18]. Two pairs of a six inch LCDs (H720 x V240 pixcells) with a convex lens system are used. Two mirrors are arranged so that the LCDs can be placed on the upper side in front of the operator. These made possible the compact arrangement of the display system suitable for the manipulation master system.

3. Experiments

Experiments which quantitatively evaluate the typical characteristics of the tele-existence master slave system were conducted.

The most important features of the tele-existence include the natural three dimensional vision (close to direct observation), which follows an operator's head movement in real time. Another feature is the natural correspondence of visual information and kinesthetic information, i.e., an operator observes the slave's anthropomorphic arm at the position where his/her arm is supposed to be.

This allows the operator at the control to perform tasks which need coordination of hand and eye quickly as in the case of direct operation. Adding to them, the use of intentional motion parallax generated by the voluntary movement of the operator's head enhances the performance.

In order to prove experimentally and quantitatively evaluate the effect of the three features of the tele-existence, the following experiments were conducted. A manipulation task of building three blocks (brick on brick) (dimension of each brick: size H62mmxW43mmxD43mm; weight 65g) which were randomly placed on a table against a natural background under natural lighting condition was assigned.

An operator was asked to move from the randomly set initial place to the place near to the table by using joy stick. He was also asked to pick up one of the three blocks placed randomly on the table and put it on another block, and pick up again the rest of the block and place on the top of the two blocks by using the master manipulator. The time elapsed from the start of the locomotion till the end of the manipulation of building three blocks was measured.

The following five visual display methods were compared:

A)CRT(O): Conventional CRT display placed in front of the operator with a field of vision of 45 degrees and a camera placed outside of the robot;
B)CRT: Conventional CRT display placed in front of the operator with a field of vision of 45 degrees and a camera placed at the eye position of the robot head,
C)HMD(M): Monocular Head Mounted Display and one of the camera mounted on the slave robot,
D)HMD(B): Binocular Head Mounted Display and

the stereo camera mounted on the slave robot,
E)HMD(M+): HMD(M) with body motion following function,
F)HMD(B+): HMD(B) with body motion following function.

The head mounted display used is designed according to the procedure which has been described in the previous reports [8,18]. In the HMD(M) mode, only the right side display of the binocular system is used. The field of vision is 40 degrees for each eye as is described in the last section.

The subject's body movement is measured by the encoders of the link mechanism. According to the motion information thus measured, the slave robot follows the subject's movement using its locomotion mechanism, which gives rise to the motion parallax. Figure 3 shows the coordinates of the locomotion system of the slave robot.

Each run of the experiment consists of 8 trials and the averages of the data were compared. Subjects were four male researchers in their twenties.

Figure 4 shows the result of the average time elapsed for the completion of the task with a standard deviation. In order to cancel the effect of the difficulty level of each trial caused by its randomly set initial starting position and randomly set blocks position, the data was normalized as follows:

$$N_{ij} = 6\, T_{ij} \,/\, \sum_{j=1}^{6} T_{ij} \,,$$

where i is the trial number and j is the condition number (conditions A to F correspond to the numbers 1 to 6, respectively). Figure 5 shows the average of 8 trials of 4 subjects and its standard deviation of the normalized data.

In order to determine the statistical significance of the aparent defferences of resultant averages for the different display types, the data were analyzed by using t-test with a risk level of 5 per cent. Figure 6 shows the statistically significant superiority of the alignment with natural correspondence of visual information and kinesthetic information, i.e., an operator observes the slave's anthropomorphic arm at the position where his/her arm is supposed to be.

Figure 7 clearly indicates the statistically significant dominance of the binocular vision, while Fig. 8 shows the statistically significant effect of the use of intentional motion parallax realzed by the head motion following function, which enhanced the performance of monocular display to the level of binocular dispaly. In the binocular display, however, the effect of intentional motion parallax was not significant. This might be caused by the saturation of the performance.

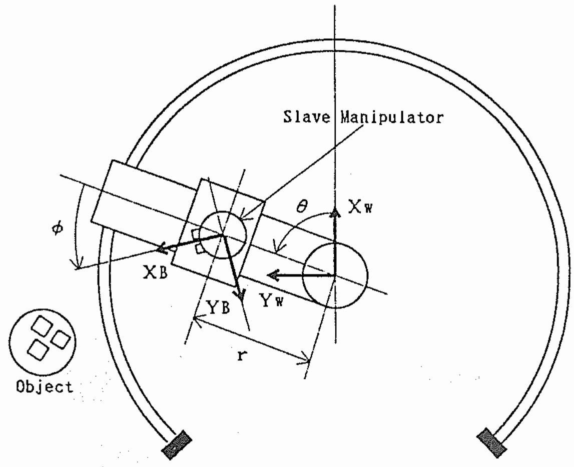

Fig.4 Experimental Arrangement.

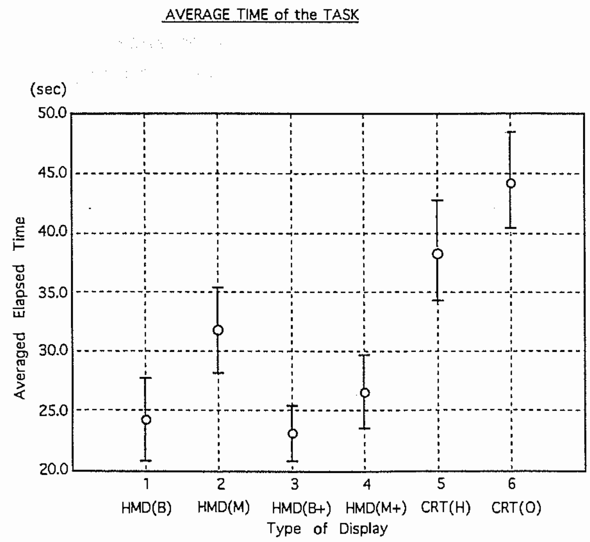

Fig.5(a) Experimental Results.
(Original Data)

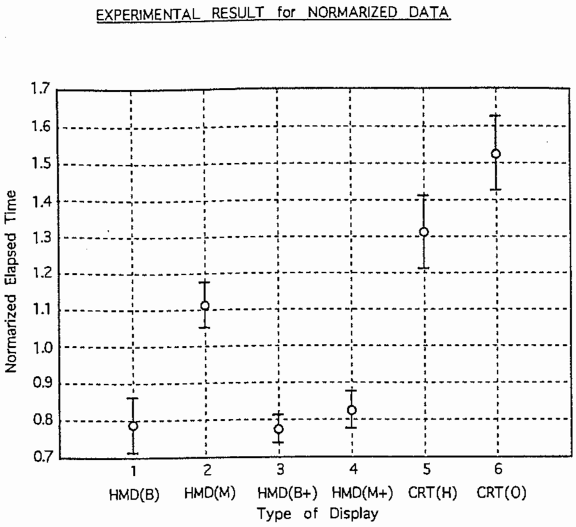

Fig.5(b) Experimental Results. (Normalized Data)

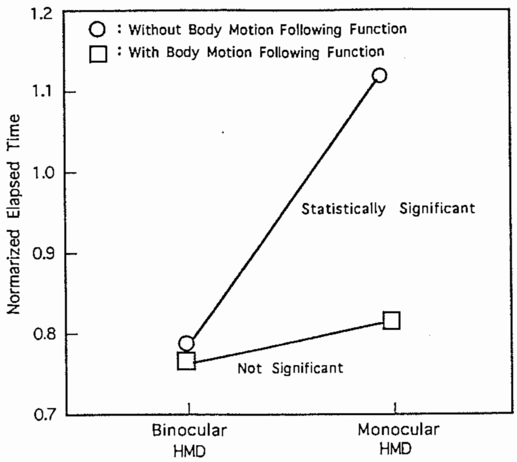

Fig.7 Effect of Binocular Vision.

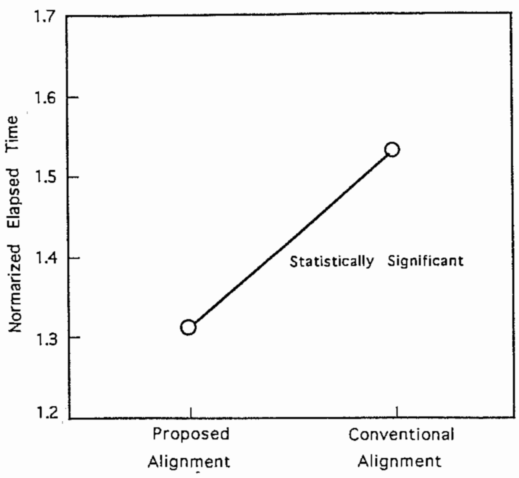

Fig.6 Effect of Coherent Alignment.

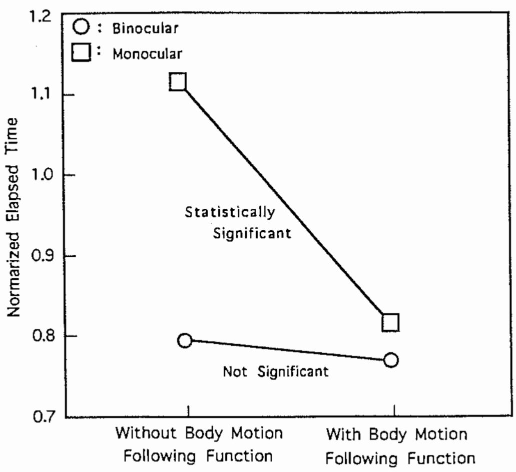

Fig.8 Effect of Intentional Motion Parallax Realized by the Body Motion Following Function.

4.Conclusion

According to the concept of tele–existence, an experimental tele–existence system is realized, which enables a human operator to have the sensation of being in a remote real environment where a surrogate robot exists. A tele–existence master slave system for remote manipulation experiments is designed and developed, and an evaluation experiment of a tele–existence master slave system is conducted. By making a comparison of a tele–existence master slave system with a conventional master slave system, efficacy of the tele–existence master slave system is verified and the superiority of the tele–existence method is demonstrated through experimental tasks.

Main conclusions are:

(1) Alignment with natural coordination of kinesthetic sensation and visual sensation has a statistically significant effect on the performance of manipulation task.
(2) Binocular vision is significantly better than monocular vision
(3) Motion parallax linked with the operator's head movement enhances monocular vision to the level of the binocular vision.

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.