Proceedings of the 4th Industrial Virtual Reality Show & Conference (IVR'96)
Tokyo Big Site, Tokyo, Japan June 12-14, 1996

R&D PROJECTS ON VIRTUAL REALITY AND/OR TELE-EXISTENCE

Susumu Tachi, Prof., Dr.

Faculty of Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113 Japan
+81-3-3812-2111 ext.6915 (phone)
+81-3-5689-7201 (fax)
tachi@star.t.u-tokyo.ac.jp (e-mail)
http://www.star.rcast.u-tokyo.ac.jp

Key Words: virtual reality, tele-existence, telepresence, haptic display, R-Cube Project

Abstract

"Virtual" is defined as "existing in effect or essence though not in actual fact or form," and virtual reality enables humans to experience events and act in a virtual environment just as if they were in essence or in effect in the real environment. Tele-existence is virtually the same concept as virtual reality, but takes a different point of view. It represents a new concept that allows humans, who are assumed to be emancipated from the restrictions of time and space, to exist in a "location" defined by inconsistent time and space, or a virtual space. The concept of the tele-existence is proposed by the author in 1980 and played the role of the fundamental principle of the eight year National Large Scale Project of "Advanced Robot Technology in Hazardous Environment" which started in 1983 together with the concept of the Third Generation Robotics. In this plenary paper, recent progress in the field of tele-existence and/or virtual reality in Japan is reviewed with emphasis on national R&D Projects.

1. Introduction

In the United States the Committee on Virtual Reality Research and Development was established by the National Research Council in 1992 at the request of the Federal Government, and the report was submitted in 1995 recommending a national research and development agenda in the area of virtual reality to guide government research and development over the generation. In Japan the Ministry of Education, which is in charge of the academic researches in Japan, selected Virtual Reality as one of the most important areas to be researched, and started the three year project of Fundamental Study on Virtual Reality from the academic year of 1995 (April 1995). The Japanese Ministry of International Trade and Industry (MITI) just launched a ten-year National Large Scale Project on virtual reality dubbed Human Media this April based on the preceding two year feasibility study. From this fiscal year MITI also started a feasibility study on networked robotics called R-Cube (Real-time Remote Robotics). These actions in both countries and other similar activities including United Kingdom, France and Germany strongly indicate the importance of virtual reality as generic technology for the 21st century. Fundamental researches and development are needed for the healthy development of the technology, which includes not only scientific and technological developments but also psychological, social and ethical considerations. In this plenary paper recent progress in virtual reality and/or tele-existence in Japan is reviewed with special emphasis on R&D projects.

2. Historical Review of Tele-Existence

Tele-existence is a concept named for the technology which enables a human being to have a real time sensation of being at the place other than the place where he or she actually exists, and is able to interact with the remote and/or virtual environment. He or she can "tele-exist" in a real world where the robot exists or in a virtual world which a computer has generated. It is possible to tele-exist in a combined environment of real and virtual. Virtual reality is a technology which presents a human being a sensation of being involved in a realistic virtual environment other than the environment where he or she really exists, and can interact with the virtual environment. Thus tele-existence and virtual reality are essentially or "virtually" the same technology expressed in different manners.

It has long been a desire of human beings to project themselves in the remote environment, i.e., to have a sensation of being present or exist in a different place other than the place they are really exist at the same time. Another dream has been to amplify human muscle power and sensing capability by using machines while reserving human dexterity with a sensation of direct operation. In the late 1960s research and development program was planned on a powered exoskeleton that a man would wear like a garment. A concept of Hardiman was proposed by General Electric Co., for example, that a man wearing the Hardiman exoskeleton would be able to command a set of mechanical muscles that multiply his/her strength by a factor of 25, yet in this union of man and machine he would feel object and forces almost as if he or she were in direct contact. However, the project was unsuccessful because of the following reasons: (1) It is potentially quite dangerous to wear the exoskeleton when we consider the malfunction of the machine. (2) Space inside the machine is quite valuable to store computers, controllers, actuators and energy source of the machine. Thus it is not at all a practical design to use it for a human operator.

With the advent of science and technology, it has become possible to challenge for the realization of the dreams. The concept of projecting ourselves by using robots, computers and cybernetic human interface is called tele-existence or telepresence. Adding to project ourselves or tele-exist in a remote real world, projecting ourselves or tele-existing in a computer generated virtual world is becoming possible. This concept is also called as virtual reality. This concept was born independently both in Japan and in the United States, and 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, and 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]. 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 for real and/or virtual environments 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].

3. Recent Researches on Tele-Existence

3.1 Evaluation Experiments of a Tele-existence Manipulation System [18]

A tele-existence manipulation system was evaluated quantitatively by comparing tasks of tracking a randomly moving target under several operational conditions. The effects of various characteristics, e.g., binocular vision and the effect of natural arrangement of the head and the arm, are analyzed by comparing quantitatively the results under these operational conditions. Human tracking transfer function was measured and was used for comparison. The results revealed the significant dominance of the binocular vision with natural arrangement of the head and the arm, which is the most important characteristic of tele-existence.

3.2 Experimental Study on Remote Manipulation using Virtual Reality [19]

In order to control a slave robot in poor visibility environments, an experimental extended tele-existence system using virtual reality was constructed. The environment model was constructed from design data of the real environment. When virtual reality is used for controlling a slave robot, the modeling errors of the environment model must be calibrated. A model-based calibration system using image measurements is proposed for matching the real environment and virtual environment. The slave robot has an impedance control system for contact tasks and for compensating for the errors that remain even after the calibration. An experimental operation in a poor visibility environment was successfully conducted.

3.3 Coherency of Kinesthetic and Visual Sensation in Virtual Reality System [20]

To realize highly realistic sensation of presence in a virtual environment, it is necessary to provide coherency between kinesthetic and visual sensation by introducing a virtual human to which a user is projected just as in the case of tele-existence to the remote robot. In order to construct such an environment, an object-oriented virtual environment description method using the class defined in C++ language is proposed, which is flexible, easy to construct, and efficient for image generation. A virtual environment of our real laboratory with the virtual tele-existence manipulation system was constructed. Using the system, an experiment was conducted to demonstrate the effectiveness of the use of a virtual human as a surrogate of the operator.

3.4 Calibration Method of Virtual Parameters for See-Through Head-Mounted Display [21]

Matching of location and size between objects in the real environment and in the virtual environment is crucial when See Through Head Mounted Display (STHMD) is used. A calibration method was proposed to cancel both systematic errors of visual parameters caused in manufacturing process and differences between actual and designed location of user's eye on STHMD. The former is required to be calibrated only once after the fabrication of STHMD's, where as the latter has to be calibrated every time a user starts using STHMD. By the calibration, the systematic error was reduced about 1 mm per target, which was less than one-thirtieth of that before calibration, where the error caused by individual difference of a user was reduced to about 2 mm

per target, which was a half of that before the calibration.

3.5 Compensation of Time Lag between Actual and Virtual Spaces by Multi-Sensor Integration [22]

Unconstrained measurement of human head motion is essential for HMD. A method was proposed to compensate the latency, which conventional magnetic sensors had, and raised the effective sampling rate through the integration of magnetic sensor and gyro sensor by using the Kalman filter. A physically consistent system model of human rotation described by quaternion and angular velocity was derived and the optimal prediction was made using the model and measurements by both sensors.

3.6 Virtual Haptic Space [23]

A method was proposed to construct a virtual haptic space driven by the same environment model of the real world as of the visual space, and a haptic graphics system was constructed according to the proposed method. A similar concept was also proposed and an experimental system was developed in USA, which is known as Robotic Graphics [24]. Human limb motion was measured in real time and the subspace of the total haptic space, which was or would be in contact with the human end effector, was constructed using the haptic space display device. Its end effector was an environment shape approximation device whose shape was specially designed to approximate several shapes by changing its sides of contact. Its position and orientation was controlled by a pantographic mechanism called an active environment display. The shape of the haptic space was approximated by the environment shape approximation device, and inertia, viscosity and stiffness of the haptic space were generated by the use of the mechanical impedance controlled active environment display.

4. R&D Projects in Japan

4.1 A Fundamental Study on Virtual Reality -Generation of Virtual Space and Human Interfaces for Virtual Environments Scientific Research on Priority Areas (1995 - 1997)

Virtual Reality was selected by the Japanese Ministry of Education, which is in charge of the academic researches, as one of the most important areas to be researched, and the three year project of the Fundamental Study on Virtual Reality started from the academic year of 1995 (April 1995) involving almost all the academicians engaged in the field of virtual reality in Japan. The following is the abstract of the research aims and scopes. For more information the following URL can be accessed: (http://www.star.rcast.u-tokyo.ac.jp/Vrjuten). Virtual reality is gradually being applied to several areas in our society today. However, fundamental research on human behavior in virtual environments and the effect of these virtual environments on human beings is only at a preliminary stage. In this study, fundamental research on virtual reality will be conducted in the following areas:

1)Elucidation of perceptual and behavioral human characteristics in virtual environments;
2)Optimal design of interface devices between human and virtual environments;
3)Establishment of virtual world construction and/or representation methods;
4)Assessment of the influence of virtual reality technology on human society and/or human health and welfare.

4.2 National Large Scale Project of "Human Media"

"Human Media" is a ten-year National Large Scale Project on virtual reality, which the Japanese Ministry of International Trade and Industry (MITI) launched from April,

1996, based on the preceding two-year feasibility study. "Human Media" means human centered media. In conventional media, humans are forced to train themselves to be accustomed to it. Even in a so called human friendly interface environment, there always media first, and humans must face it later, however friendly it is. It was perfectly all right in the old days, when the progress of machines was slow, thus the alternation of generations solved the problem. Youngsters learned a new system using their flexibility and became accustomed to it. They became experts when they came of age. However, recent speed of progress makes it impossible for us to rely on the alternation of generations. Even the system which humans learned when they are young become old in ten years or less. Humans are quite accustomed to the natural environment and also conventional man-made environment and tools, like houses, rooms, desks, or notebooks, for they exist with us through generations. "Human Media" tries to create such virtual environments that we are accustomed to through generations as the interface environment to any systems. In order to attain the goal of "humans first" instead of "media first", real time three dimensional interactive virtual space that has the very characteristics of the physical real world and real conventional objects and/or tools is being sought. In this ten year project, virtual reality, humane perceptual and behavioral characteristics known as "kansei", and autonomous intelligent computer interface technology like "agents" are being studied from the standpoint of designing the ideal human centered media environment.

4.1 National Feasibility Study of "R-Cube"

"R-Cube" or, Real time Remote Robotics, is a two year national feasibility study, which started in April, 1996. The aim of the study is to establish a new concept of networked robotics and virtual reality, and to design an ideal system for the realization of the concept. Today's computer network like internet made world wide communication a reality. However, it lacks the capability of conducting something real by interacting with the real environment. In order to enable human users of a network to conduct real work through the network, the idea of R-cube is proposed. The concept of the project is to have robots as one of the terminal devices of computers, which are connected by the network like B-ISDN. A human user can access one of the robots which are registered, and is able to "tele-exist" in the robot with permission. This can be done either at home, in the remote office or at any place which has the VR interface capability connected with the network (http://www.irofa.com). Fundamental technologies such as networked tele-existence, personal virtual reality interface, surrogate robot intelligence for the safety of human beings, and tele-existence data transmission protocol are being researched.

5. Conclusion

On May 27, 1996, the Virtual Reality Society of Japan (VRSJ) was established (e-mail: vrsj@star.rcast.u-tokyo.ac.jp;URL: http://yindy1.aist-nara.ac.jp/VR/). It is the academic society on virtual realty consisting of scholars, researchers, engineers, physicians, surgeons, artists in the fields of not only engineering but also medicine, psychology, physiology, and art. It is organizing its first annual conference at Olympic Memorial Center in Tokyo from October 8 through 9, 1996, and co-organizing the 2nd International Conference on Virtual Systems and Multimedia (VSMM'96) at Gifu Convention Center, Gifu from September 18 through 20, 1996 (http://www.ojk.info.gifu-u.ac.jp /vsmm/96/index.html), and the 6th International Conference on Artificial Reality and Tele-Existence (ICAT'96) at Makuhari, Chiba from November 20-22, 1996 (http:// yindy1.aist-nara.ac.jp/ VR/icat96-cfp). This society is expected to play the leading role for the healthy development of virtual realty science and art together with the national large scale projects such as Human Media and R-Cube.

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]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.

[8]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.

[9]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.

[10]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.

[11]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.

[12]T.B.Sherdan: Telerobotics, Automation and Human Supervisory Control, MIT Press, 1992.

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

[19]E.Oyama, N.Tsunemoto, S.Tachi and Y.Inoue: Experimental Study on Remote Manipulation using Virtual Reality, Presence, vol.2, no.2, pp.112-124, 1993.

[20]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.

[21]T.Oishi and S.Tachi: Calibration Method of Visual Parameters for See-Through Head-Mounted Display, Presence, vol.6, no.1, 1996.

[22]S.Emura and S.Tachi: Compensation of Time Lag between Actual and Virtual Spaces by Multi-Sensor Integration, Proceedings of the 1994 IEEE International Conference on Multisensor Fusion and Integration of Intelligent Systems (MFI'94), pp.463-469, Las Vegas, NV, October 1994.

[23]S.Tachi, T.Maeda, R.Hirata and H.Hoshino: A Construction Method of Virtual Haptic Space, Proceedings of the 4th International Conference on Artificial Reality and Tele-Existence (ICAT'94), pp.131-138, Tokyo, Japan, July 1994.

[24]W.McNeely: Robotic Graphics: A New Approach to Force Feedback for Virtual Reality, Proceedings of the 1993 IEEE Annual Virtual Reality International Symposium (VRAIS), pp.336-341, Seattle, Washington, September 1993.