VIRTUAL REALITY IN ROBOTICS

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Abstract:

The American Heritage Dictionary defines "virtual" as "existing in essence or effect though not in actual fact or form," and this definition also applies to virtual reality (VR) per se. For the VR users, the "virtual reality" exists "in effect or in essence" although "not in actual fact or form." The Japanese national project, "Fundamental Study on Virtual Reality -Generation of Virtual Space and Human Interfaces for Virtual Environments-," tries to clarify how the man made environment can be made "virtual" for human beings in the above sense. On the other hand, the concept of telexistence (tele-existence), i.e., virtual existence in a remote or computer-generated environment, has developed into a national R&D scheme of R-Cube (Real-time Remote Robotics). Based on the scheme the National R&D Project of "Humanoid and Human Friendly Robotics" was launched in April 1998. In this plenary paper, these two Japanese national projects on virtual reality and robotics are introduced and related basic studies are discussed from the standpoint of virtual reality in robotics.

Key words: Virtual Reality, Telexistence, Tele-Existence, R-Cube, Real-time Remote Robotics, Sensation of Presence, Sensation of Existence

1. Introduction

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 existing in a different place other than the place they 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 strength by a factor of 25, yet in this union of man and machine he would feel object and forces almost as if he were in direct contact. However, the project was unsuccessful because of the following reasons: (1) it is potentially quite dangerous to wear a powered 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 again. The concept of projecting ourselves by using robots, computers and cybernetic human interface is called telexistence (tele-existence). Adding to project us or telexist (tele-exist) in a remote real world, projecting ourselves or telexist in a computer-generated virtual world is becoming possible. The latter concept is called virtual reality in a narrow sense.

The concept of the telexistence was proposed by the author in 1980 and it played the role of the fundamental principle of the eight year Japanese National Large Scale Project of "Advanced Robot Technology in Hazardous Environment" which started in 1983 together with the concept of the Third Generation Robotics. Through this project theoretical consideration has been done and systematic design procedure has been established. Experimental hardware telexistence system haven been made and the feasibility of the concept has been demonstrated.

In order to realize the society where everyone can freely telexist anywhere through network, Japanese Ministry of International Trade and Industry (MITI) proposed a long-range national R&D scheme, which is dubbed R-Cube (Real-time Remote Robotics) in 1995.[1]

Based on the scheme and after two-year feasibility study called Human Friendly Network Robot (FNR), which was conducted from April 1996 till March 1998, National Applied Science & Technology Project "Humanoid and Human Friendly Robotics" has just been launched. It is a five-year project toward the realization of so-called R-Cube Society.

On the other hand, basic study toward the elucidation of a sensation of presence has been carried out. The Japanese national project, "Fundamental Study on Virtual Reality -Generation of Virtual Space and Human Interfaces for Virtual Environments-," started in 1995 to clarify how the computer-generated environments can be made effectively or essentially the same as the real environments. Computer-generated environments can be called virtual environments only if they are effectively or essentially the same as the real environments.

In this plenary paper these two projects on virtual reality and texistence in Japan are introduced and discussed from the standpoint of virtual reality in robotics.

2. Fundamental Study on Virtual Reality - Generation of Virtual Space and Human Interfaces for Virtual Environments-

Virtual reality is a technology which enables a human being to "virtually" exist in a computer-generated environment or a remote environment where his/her surrogate exists and can gain various experiences, can communicate with others and can conduct tasks while interacting with the virtual environment. This technology 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.

The Japanese national project of "Fundamental Study on Virtual Reality -Generation of Virtual Space and Human Interfaces for Virtual Environments-, " was launched in 1995 supported by the Ministry of Education, Science, Sports and Culture (Monbusho) as a Priority Scientific Research Area. The project is led by the author (Prof. S. Tachi of the University of Tokyo), and more than 200 professors and researchers of the universities in Japan joined the project. In this study, fundamental research on virtual reality has been conducted in the following groups: [1]

1)Elucidation of perceptual and behavioral human characteristics in virtual environments (Group Leader: S. Tachi).

2)Optimal design of interface devices between human and virtual environments (Group Leader: M. Sato).

3)Establishment of virtual world construction or representation methods (Group Leader: M. Hirose).

4)Assessment of the influence of virtual reality technology on human society and/or human health and welfare (Group Leader: T. Ifukube).

Some of the results can be seen by visiting the following Web site: http://www.star.rcast.u-tokyo.ac.jp/Vrjuten/

3. Elucidation of Perceptual and Behavioral Human Characteristics in Virtual Environments [1,2]

Virtual space constructed for virtual reality must have three basic characteristics, i.e., 1) three dimensional space structure which faithfully represents the original spatial structure, 2) three dimensional constructed virtual space which follows precisely to head and/or torso movement and human real time interaction with the constructed space, and 3) self projection, i.e., coherent sensation of proprioception with vision, audition and taction.

The above three conditions are satisfied in a telexistence system. By using a telexistence system, a human operator has a feeling of being inside a remote robot with three dimensional visual and auditory sensation controlled precisely by the motion of the operator, and a manipulator interacting with an environment, which is seen at the place where his/her real arm is felt by his/her propioception.

A telexistence manipulation system was constructed and 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, were 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 demonstrated the importance of the above three conditions of virtual reality (the three conditions of VR).

The concept of telexistence in a remote environment using a surrogate robot is easily extended to the telexistence in computer-generated environment using a surrogate virtual human, which satisfies the three conditions of VR.

The aim of the study is to elucidate the human perceptual and behavioral mechanisms in three dimensional space using computer-generated virtual environments, especially to elucidate how a sensation of presence or a sensation of existence emerges.

Fig.1 shows an example of the approach. A human subject is asked to interact with a computer generated virtual environment, of which spatial parameters are controlled by the computer, while the human movement and/or internal status are measured in real time and is used to evaluate quantitatively the sensation of presence by comparing his/her behavior in the real environment as a control.

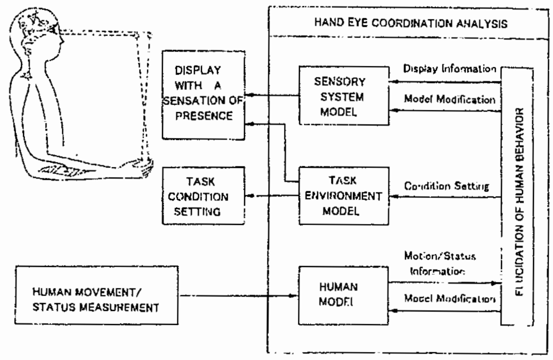

Fig. 1 Schematic Diagram on an Approach to the Elucidation of Human Perceptual and Behavioral Characteristics

A human perceptual and behavioral model will be proposed and tested by inputting the same virtual environment and observing the output behavior of the model. By modifying the model to show the same behavior of the real human, the perceptual and behavioral model will be obtained.

In the next section, an example is shown of such an experimental environment constructed as a virtual haptic and visual space where a subject can feel an object where he/her sees.

4. Construction of Virtual Haptic Space for Elucidation of Perceptual and Behavioral Human Characteristics in Virtual Environments [3]

A method has been proposed to represent haptic space with edges, vertices and surfaces with mechanical impedance information. The system is intended to provide not only force feedback but also shape information of the contact object during large space interaction with surfaces of various shapes and mechanical impedance. A user wears a lightweight passive seven-degree of freedom exoskeleton goniometer that measures the position and orientation of a fingertip.

A six-degree of freedom manipulator, which we call "Active Environment Display (AED)," moves to anticipate and if necessary counter the user's action to display contact with virtual surfaces, edges and vertices. The robot manipulator is a pantograph with range of motion of 60x60x60 cm for translation and 360, 180, and 135 degrees for yaw, roll, and pitch, respectively.

The wrist of the manipulator carries a device with a complex surface geometry as well as convex and concave edges and flat surfaces. It is thus possible to simulate contact with continuous surfaces and edges by moving the Shape Approximation Device (SAD). Contiguous surfaces are displayed by reorienting the corresponding facet of SAD. A User wears a head-mounted display, which immerses him/her in the virtual environment.

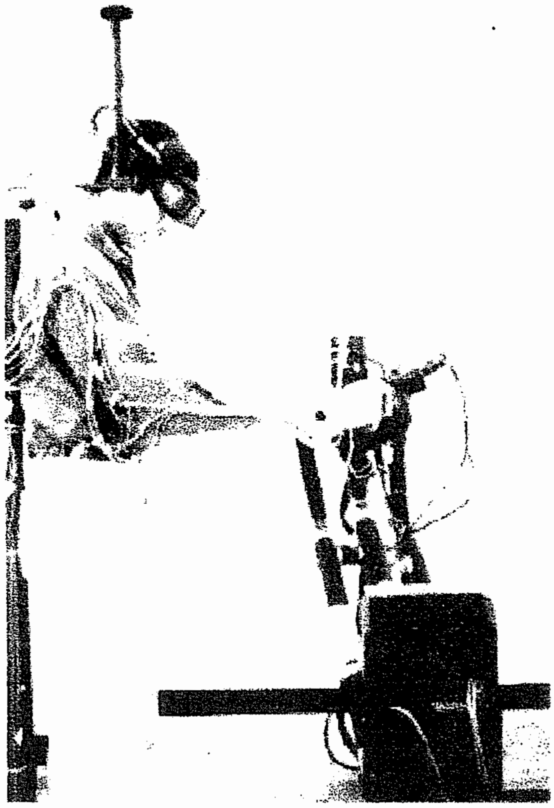

Fig. 2 General View of the Haptic Graphic Device which Generates Shape of a Virtual Object

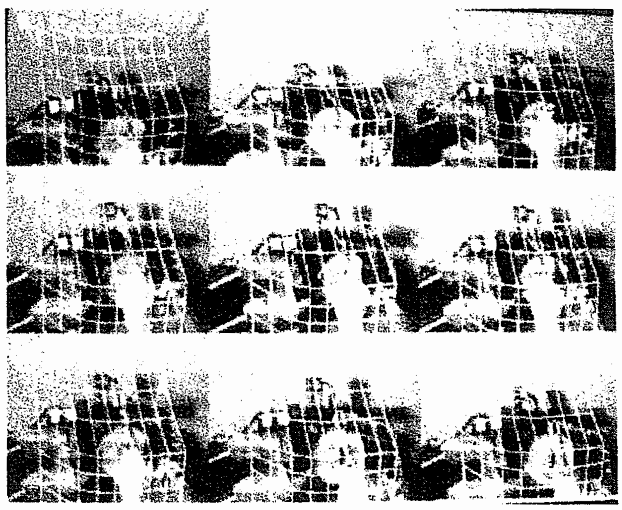

Fig. 3 Construction of Two Surfaces with an Edge

Thus the user can feel exactly what (s)he sees at the position it is observed with the haptic shape just as it is seen. Experiments are conducted to present several shape objects with several kinds of mechanical impedance. It has been shown that an object shape with vertices, edges and surface can be represented. Concave edges as well as convex edges are represented successfully using the test hardware [3]. Effect of touching the same shape exactly at the same place as is seen is now being evaluated.

5. Mutual Telexistence

In our first reports [4], the principle of the telexistence (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 a sensation of presence was demonstrated by psychophysical experiments using the test hardware. A method was also proposed to develop a mobile telexistence system, which can be remotely driven with the auditory and visual sensation of presence. A prototype mobile televehicle system was constructed and the feasibility of the method was evaluated [5]. In order to study the use of the telexistence system in the artificially constructed environment, the visual telexistence simulator was designed, a quasi-real-time binocular solid-model robot-simulator was made, and its feasibility was experimentally evaluated [6].

The first prototype telexistence master slave system for remote manipulation experiments was designed and developed [7,8], and a preliminary evaluation experiment of telexistence was conducted. An experimental telexistence system for the virtual environment was designed and developed, and by conducting an experiment in the virtual environment was demonstrated experimentally[9]. Quantitative evaluation of the telexistence manipulation system was conducted through tracking tasks by using a telexistence master slave system designed and developed [10].

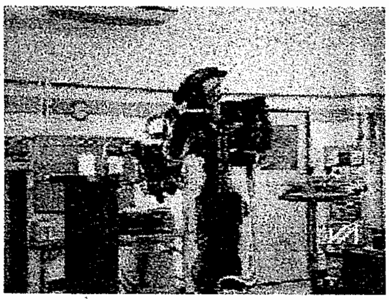

Fig. 4 Telesar (Telexistence Surrogate Anthropomorphic Robot)

Through these experimental studies, it has been demonstrated that human beings can telexist in a mutual remote environment and/or a computer-generated mutual environment by using the telexistence system constructed [11,12].

However, it was not possible to project the real time figure of a human being into the virtual environment using the system. In order to have natural three-dimensional figures of the human beings in a mutual computer-generated virtual environment, it is necessary to build a telexistence system that can project real human beings into the virtual environment in real time.

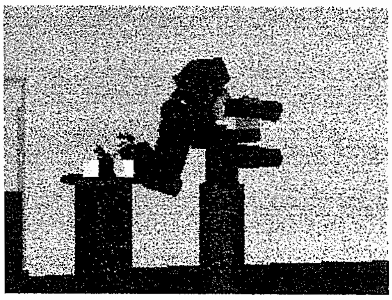

Fig. 5 Virtual Telesar at work

A method is proposed to project humans virtually in a mutual virtual environment using captured real pictures of the human beings. Each user is inside a booth, which both displays the virtual environment and captures the picture of the user in real time from the viewpoints of other users. The captured image is texture-mapped on a virtual board (alpha plane) in the mutual virtual environment at the position of the observed virtual human, the direction of which is arranged by the viewing direction of the observing human. The observing human sees the computer generated virtual environment with the figures of other users occluding or being occlude by virtual objects in the virtual environment changing according to the observer's movement in real time.

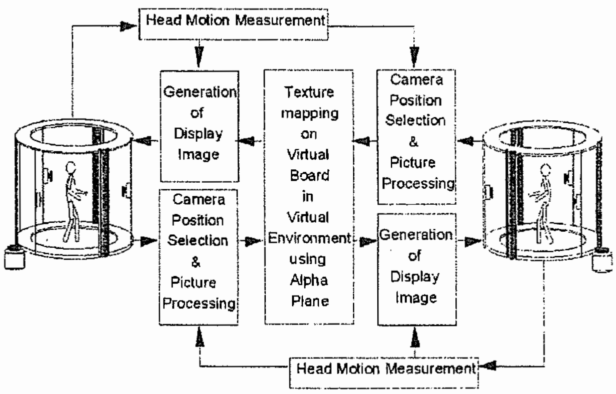

Fig. 6 Telexistence Booth for mutual telexistence

An experimental hardware was constructed based on the concept. Although it separated the functions of display and capture and were not operated in real time, observers all reported that they saw convincing three-dimensional figure of another user in a computer generated mutual virtual environment. Thus the test hardware successfully demonstrated the feasibility of the concept [13]. The author and colleagues are constructing the second version of the hardware system with full specification based on this feasibility experiment.

6. R-Cube (Real-time Remote Robotics)

R-Cube stands for the Real-time Remote Robotics. This concept was proposed by the Japanese Ministry of International Trade and Industry (MITI) in 1995. The concept is the research and development of the technologies that enable human users to telexist freely by using robots, virtual reality and network technology [14].

Figure 7 and Fig.8 show examples of the conceptual networked telexistence application using R-Cube robots.

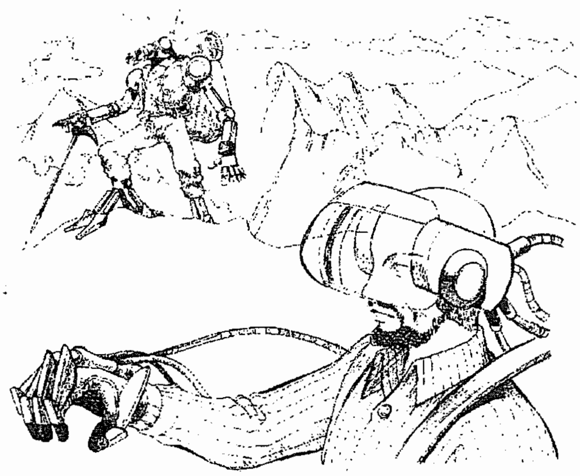

Fig. 7 Conception of Mountain Climbing using R-Cube Robot

Based on the national R&D scheme of R-Cube, the project of "Humanoid and Human Friendly Robotics" was launched in April 1998 by the Agency of Industrial Science and Technology (AIST). The outline of the project is as follows: [15]

Japan's population is aging rapidly and people are having fewer children. This means that efficient and human friendly machinery that can support daily life and the activities of humans, such as attending to the elderly and the handicapped, is in great demand. Thus, this project aims to develop a safe and reliable human friendly robot system capable of carrying out complicated tasks and supporting humans within the sphere of human lives and activities. Through development of such a system, this project will contribute towards improvement in efficiency and safety in industry, making society and the living environment more convenient and comfortable and towards the creation of new industries in the manufacturing and service sectors.

This project will be undertaken in two phases. The goal of phase one is to develop a platform (basic research models) for human friendly and supportive robot systems by bringing together the elemental technologies possessed by industry, academia and the government with the latest technologies. To be specific, R&D will be carried out on the following themes as specified in the attached plans.

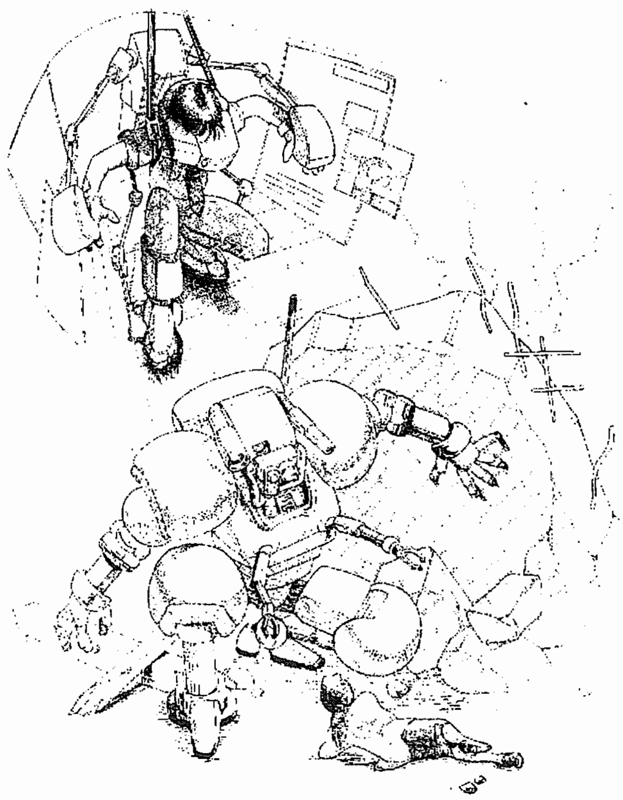

Fig. 8 Conception of Rescue Operation using R-Cube Robot

1) Development of a platform for a human friendly and supportive robot

2) Development of a virtual platform for a human friendly and supportive robot

In phase two, R&D will be carried out towards the application of human friendly and supportive robots with consideration given to the needs of industries in which such robots might be used. Improvement and addition of elemental technologies will be carried out using the platform and the virtual platform developed in phase one. R&D will be carried out on the following theme as specified in the attached plans.

3) Application of a platform for a human friendly and supportive robot

This R&D aims to be highly efficient by taking full advantage of the research potential of research groups from industry, academia and government. To achieve this, a large-scale and concentrated method of R&D which brings together all researchers under the leadership of a project leader will be used.

Description of Research and Development is as follows:

This R&D aims to develop a safe and reliable human friendly robot system capable of carrying out complicated tasks and supporting humans within the sphere of human lives and activities. A platform for such a robot will be developed and application technology for robots will be developed using the platform.

Research and Development will be implemented as follows:

1) Development of a platform for a human friendly and supportive robot: Human friendly and supportive robots capable of basic motions and movements within human work and living environments and having communication ability and main parts consisting of modular structures making the addition and modification of functions easy will be developed. A teleoperation system will also be developed.

2) Development of a virtual platform for a human friendly and supportive robot: A virtual platform consisting of a simulator and software for operating platform hardware and a simulator will be developed.

7. Conclusion

Virtual reality must have the essence of the reality in its computer-generated environment or transmitted remote environment so that it is effectively the reality itself. In order to realize virtual realty in the above sense, it is clear that technologies of human measurement, environment measurement, robot control, and environment control must play very important roles. Thus ISMCR (International Symposium on Measurement and Control in Robotics) Committee organized topical workshops on Virtual Reality and Advanced Human Interfaces in Houston in 1994 and in Tampere in 1997. The third one is now being planned in Tokyo in 1999.

One of the most promising technologies today is the integration of virtual realty and robotics on the network. It is called networked robotics in general and R-Cube (Real-time Remote Robotics) in particular. R-Cube is a Japanese national R&D scheme toward the realization of the mutual telexistence through various kinds of networks including the Internet. Japanese Ministry of International Trade and Industry (MITI) launched the "Humanoid and Human Friendly Robotics" 5-year Project in April 1998. This is the first step toward the realization of R-Cube and the results are quite much expected.

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