Toward the Next Generation Telexistence

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Abstract: Telexistence (tel-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 environments. He or she can "telexist" (tel-exist) in a real world where the robot exists or in a virtual world that a computer has generated. It is also possible to telexist in a mixed environment of real and virtual, which can be called augmented telexistence. It enables a human operator to have a sensation of being in a remote real environment where a surrogate robot exists, while being augmented by a virtual environment synthesized by a computer, whose structure is based on the sensor information on board the robot. In this keynote paper, the concept of telexistence is explained and experimental telexistence systems are introduced. The concept of telexistence, i.e., virtual existence in a remote or computer-generated environment, has developed into a national R&D scheme of R-Cubed (Real-time Remote Robotics) for the advanced and comfortable life of the 21st century network society. R-Cubed can be said to be the effort toward the next generation of telexistence. Based on the scheme the National R&D Project of "Humanoid and Human Friendly Robotics," HRP in short, was launched in April 1998. This is an effort to integrate telerobotics, network technology and virtual reality into networked telexistence. A next generation telexistence technology using HMP (Head Mounted Projector) and retro-reflective screen is also proposed and feasibility experiments are conducted.

Keywords: telexistence, tele-existence, telepresence, virtual reality, master-slave manipulation

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 potential malfunction of the machine. (2) Space inside the machine is quite valuable to store computers, controllers, actuators and energy source of the machine, which eliminated the space for a human operator. Thus, the design proved impractical in its original form.

With the advent of science and technology, however, it has become possible to challenge for the realization of the dreams again with a different concept. The concept of projecting ourselves by using robots, computers and cybernetic human interface is called telexistence (tel-existence). This concept expands to include projection in a computer-generated virtual environment. Figure 1 illustrates the original idea of telexistence using the original figure published in 1982 in Japanese and in 1984 in English [1].

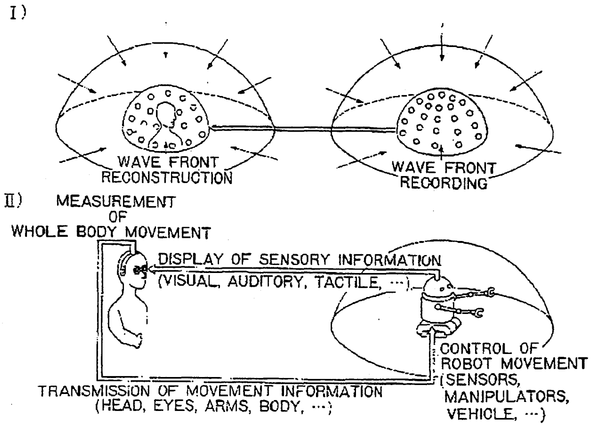

Fig. 1 Principle of Telexistence [1].

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 our first reports [1], the principle of the telexistence 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 appartus (Fig.2).

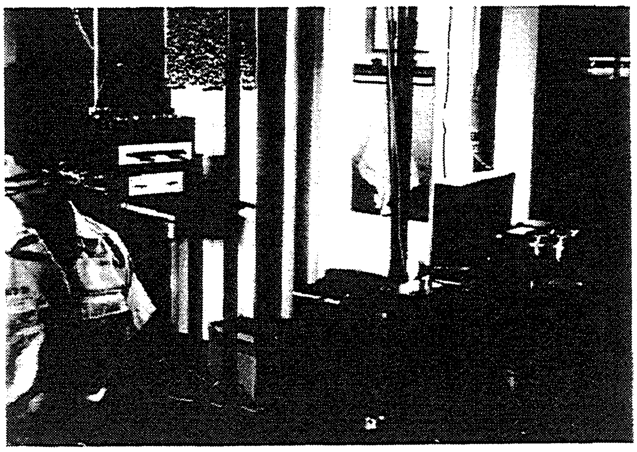

Fig. 2 First Experimental Apparatus Constructed .

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 tele-vehicle system was constructed and the feasibility of the method was evaluated [2]. Figure 3 shows the telexistence vehicle during an experiment.

The first prototype telexistence master slave system for remote manipulation experiments was designed and developed, and a preliminary evaluation experiment of telexistence was conducted. An experimental telexistence system for real and/or virtual environments was designed and developed, and by conducting an experiment comparing a telexistence master-slave system with

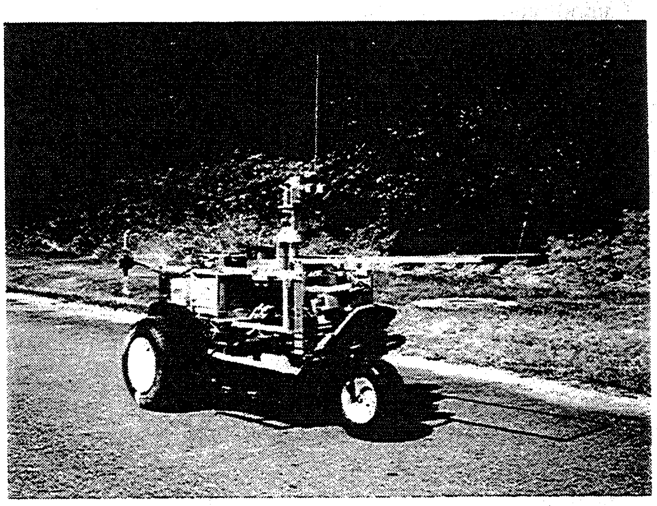

Fig. 3 Mobile Telexistence Vehicle [2].

conventional master-slave system, efficacy of the telexistence master-slave system and the superiority of the telexistence method was demonstrated experimentally (Fig.4) [3, 4, 5].

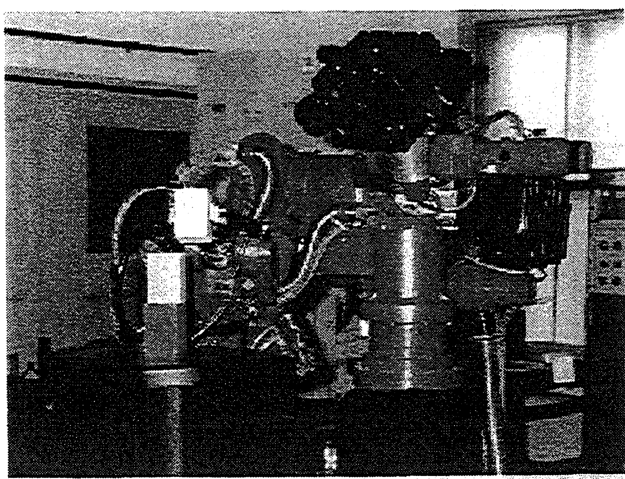

Fig. 4 Telexistence Surrogate Anthropomorphic Robot (TELESAR) at Work [5].

2. Augmented Telexistence

Telexistence can be divided into two categories: telexistence in the real world that actually exists at a distance, and is connected via a robot to the place where the user is located; and telexistence in the virtual world that does not actually exist but is created by a computer. The former can be called "transmitted reality," while the latter is "synthesized reality." The synthesized reality can be classified into two, i.e., a virtual environment as a model of the real world and a virtual environment of an imaginary world. Combination of transmitted reality and synthesized reality, which is called mixed reality, is also possible and has a great importance in real applications. This we call augmented telexistence to clarify the importance of harmonic combination of real and virtual worlds in this paper.

Augmented telexistence can be used in several situations. Take for instance, of controlling a slave robot in a poor visibility environment. An experimental augmented telexistence system using a virtual environment is constructed. The environment model is also constructed from the design data of the real environment. When augmented 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 a virtual environment. The slave robot has impedance control mechanism 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 by using Telesar (Fig.4) and the virtual Telesar (Fig.5). Figure 5 shows the virtual telexistence anthropomorphic robot used in the experiment and Fig. 6 shows how the real environment is augmented by the computer model [6,7].

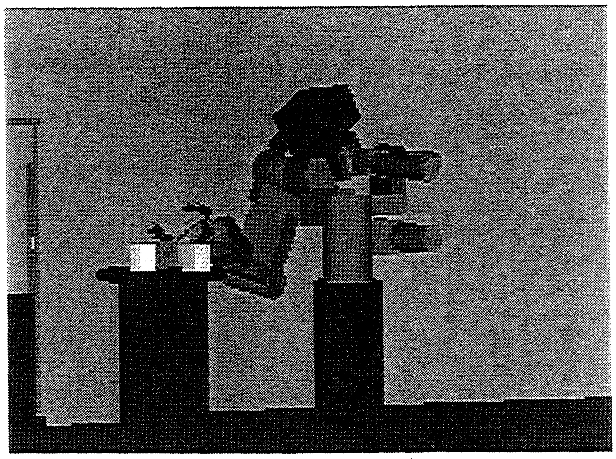

Fig. 5 Virtual TELESAR at Work.

Quantitative evaluation of the telexistence manipulation system was conducted through tracking tasks by using a telexistence master slave system designed and developed.

Through these experimental studies, it has been demonstrated that a human being can telexist in a remote environment and/or a computer-generated environment by using the dedicated telexistence system [5].

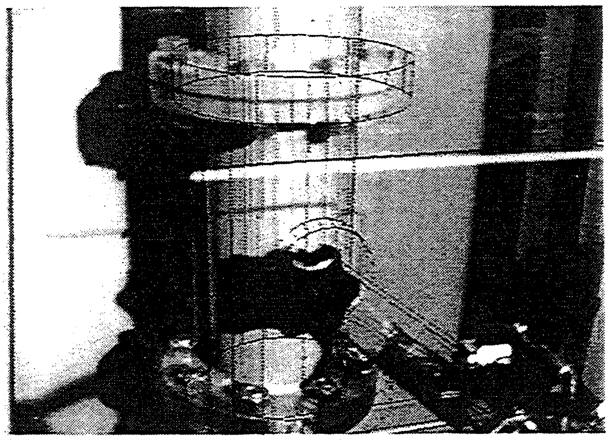

Fig. 6 An Experimental Augmented Reality.

However, it is difficult for everyone to telexist freely through commercial networks like the Internet or the next generation world-wide networks.

3. R-Cubed & HRP

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-Cubed (Real-time Remote Robotics) in 1995 [8,9].

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 (HRP)," has just been launched. It is a five-year project toward the realization of so-called R-Cubed Society by providing humanoids, control cockpits and remote control protocols.

Figure 7 shows an example of an artist's image of a future use of R-Cubed System. In this example, a handicapped person climbs a mountain with his friends using networked telexistence.

In an R-Cubed system, each robot site has its server of its local robot. The robot type varies from a humanoid (high end) to a movable camera (low end). A virtual robot can also be a controlled system to be telexisted.

Each client has its teleoperation system. It can be a control cockpit with master manipulators and a head mounted display (HMD) or CAVE Automatic Virtual Environment (CAVE) on the high end. It is also possible to use an ordinary personal computer system for its control system on the low end. In order to support the low end users to control remote robots through networks, RCML/RCTP (R-Cubed Manipulation Language / R-Cubed Transfer Protocol) is now under development [9].

To standardize the following control scheme, a language called RCML, which describes a remote robot's features

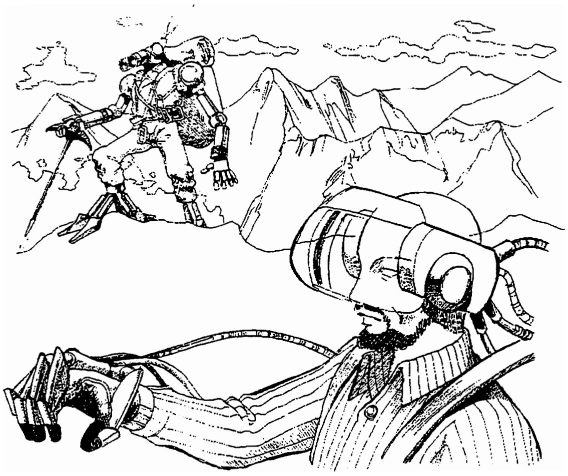

Fig. 7 Mountain Climbing using R-Cubed.

and its working environment, has been proposed. A communication protocol RCTP, which is designed to exchange control commands, status data, and sensory information between the robot and the user, has also been developed.

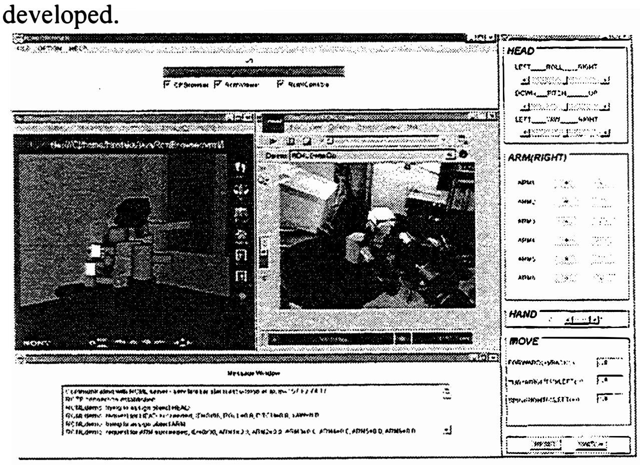

Fig. 8 An Example of an RCML Browser [8].

With a Web browsers a user accesses a Web site describing information of a robot in the form of hypertext and icon graphics using WWW browser. Clicking on an icon downloads the description file, which is written in RCML format, to the user's computer and launches the RCML browser. The RCML browser parses the downloaded file to process the geometry information, including the arrangement of the degrees of freedom of the robot, controllable parameters, available motion ranges, sensor information, and other pertinent information. The browser decides what kind and how many devices are required to control the remote robot. It then generates a graphical user interface (GUI) panel to control the robot, plus a video window that displays the images "seen" by the robot and a monitor window that lets users observe the robot's status from outside the robot. If the user has a device such as 6 degrees-of-freedom (DOF) position/orientation sensor to indicate the robot-manipulator's endpoint, the user can employ that instead of the conventional GUI panel (See Fig.8).

4. The Next Generation

A Head Mounted Display (HMD) and a CAVE are two typical virtual reality visual displays. Although they are quite useful displays, it is also true that they have some demerits. The former has a problem of tradeoff of high resolution and wide field of view, and the latter has a problem of a shadow of user's body on a virtual environment and interaction of user's virtual body with their real body.

In our laboratory at the University of Tokyo, a new type of visual display is being developed [10]. It is called X'tal vision, and it uses retro-reflective material as its screen.

A projector is arranged at the conjugate position of a user's eye, and an image is projected on a screen made of, painted with, or covered with retro-reflective material. A pinhole is placed in front of the projector to secure adequate depth of focus (Fig.9).

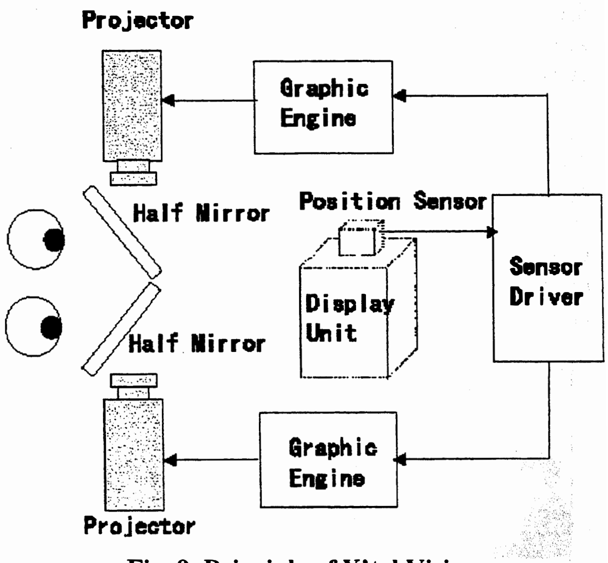

Fig. 9 Principle of X'tal Vision.

The retro-reflector screen together with the pinhole assures that the user always sees images with accurate occlusion relations. It means that if the user's body has retro-reflector on it, their body becomes a part of the virtual environment and it disappears, and their virtual body replaces it, while if it does not have retro-reflector on it, it will occlude the virtual environment without any troublesome hindrance shadow on the virtual environment.

In the construction of X'tal vision, screen shapes are arbitrary, i.e., any shape is possible. It is due to the characteristics of the retro-reflector and the pinhole in the conjugate optical system. By using the same characteristics of X'tal vision, binocular stereo vision becomes possible using only one screen with an arbitrary shape. This can be mounted on a head of a user, which we call HMP (Head Mounted Projector) System.

Almost eighteen years have passed since our first idea and concept of telexistence, and it is now possible to telexist in the remote environment and/or virtual environment with a sensation of presence. We can have feelings that we are present in several real places and can work and act. However, those people in the place where someone telexists using a robot see only the robot but they can not feel that the person presents. It is useless to use TV display on board the robot to show the face of the user. It is just comical and far from reality.

Figure 10 illustrates the proposed method of mutual telexistence using X'tal vision HMP (Head Mounted Projector) in order to solve the above problem, i.e., to make a telexisted robot look like the user of the robot. This is an effort toward the next generation telexistence.

A human user "A" uses his telexistence robot "A" at the remote site where another human user "B" is present. The user "B" also uses another telexistence robot "B", which exists in the site where the user "A" works. Both robots are painted with retro-reflective material and can act as screens, and they are controlled by their users as conventional telexistence robots.

Remote scenery sensed by cameras on board the robots "A" and "B" are sent to HMPs of human users "A" and "B", respectively. 3-D image observed by the telexistence robot "A" is projected and seen by the human user "A" with a sensation of presence, while 3-D image observed by the telexistence robot "B" is projected and seen by the human user "B" with a sensation of presence.

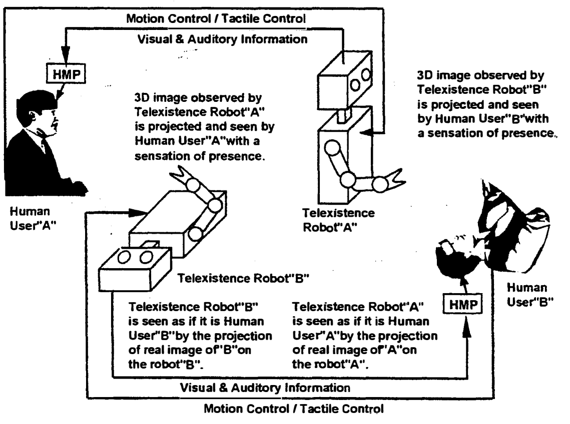

Fig. 10 Next Generation Telexistence [11].

The telexistence robot "B" is seen as if it is the human user "B" by the projection of real image of "B" on the robot "B", while the telexistence robot "A" is seen as if it is the human user "A" by the projection of real image of "A" on the robot "A".

Thus mutual telexistence becomes possible by using X'tal vision method, i.e., not only the user sees other people naturally but also the user of the robot can be observed naturally by other people. We are now in the process of feasibility study of the proposed method using Telesar.

Figure 11 shows an example of how a robot can be seen by a human being who wears a HMP. It can be seen as if the robot is a human being telexisting in the robot. Figure 11(A) shows an miniature of the HONDA Humanoid Robot, while Fig. 11(B) illustrates the robot painted with retro-reflective material. Figures 11(C) and (D) show how they are seen by a human being wearing a HMP. The telexisted robot just looks like the human operator of the robot, and telexistence can be naturally done.

5. Conclusion

Virtual means "existing in effect or in essence though not in actual fact or form." Thus virtual reality must have the essence of the reality in its computer-generated environment or a transmitted remote environment so that it is effectively the reality itself. 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-Cubed (Real-time Remote Robotics) in particular. R-Cubed is a Japanese national R&D scheme toward the realization of the next generation telexistence through various kinds of networks including the Internet. Japanese Ministry of International Trade and Industry (MITI) launched the 5-year Pr ›ject "Humanoid and Human Friendly Robotics (HRP)" in April 1998. This is the first step toward the realization of R-Cubed, the next generation telexistence, and the results are quite much expected.

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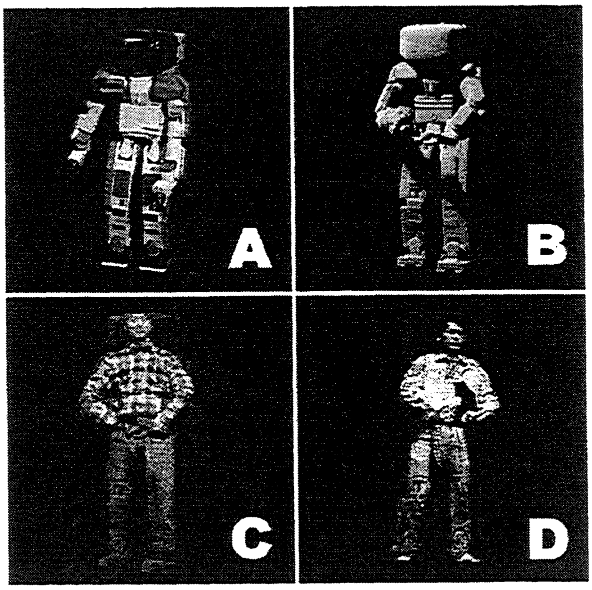

Fig. 11 (A) Miniature of the HONDA Humanoid Robot, (B) Painted with Retro-reflective Material, (C) An Example of Projecting a Human Image on it, (D) Another Example [11].