Tele-existence Through Video

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Keywords: Tele-existence, Telepresence, Artificial reality, Virtual reality, Network

1. Introduction

Tele-existence[1-8] 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. The concept of tele-existence was proposed by Tachi et al. in early 1980s. Although tele-existence has its technological basis on the field of robotics and tele-operation, researchers who are interested in a number of fields, such as tele-communication, human interface, computer simulation/graphics, computer-aided design, three-dimensional art, etc., found that the key concept can be shared among those fields of research. The concept of tele-existence, telepresence, virtual reality, and artificial reality can be considered as the same in essence.

In this paper, a historical review of the tele-existence technology is shown and the future concept of tele-existence over network is introduced.

2. Previous Researches and Applied Examples

2.1 Previous Project in Japan

Tele-existence was adopted as the main concept for the large national project, entitled Advanced Robot Technology (Research and Development of Task Robot for Potentially Dangerous Working Environments), and played a major role in that project. The technical feasibility of the tele-existence system has been proved both theoretically and experimentally through a series of tests conducted on prototype hardware models.

2.2 An Example of Tele-existence System at Laboratory

Tachi et al. has developed a prototype hardware system to show the feasibility of tele-existence system. The prototype system consists of a master system, a slave robot, and several computers used for control. In this system, the operator's motion is measured by the

master system, and the slave robot is controlled so that it follows the operator's motion in real time. The slave robot is equipped with a pair of stereo cameras, which supplies the image fed back to the operator.

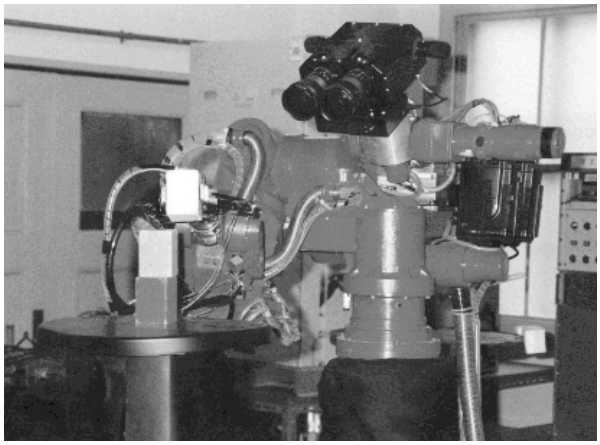

Figure 1: tele-existence slave anthropomorphic robot

Figure 1 shows the tele-existence slave anthropomorphic robot. The slave anthropomorphic robot (TELESAR) has 14 degrees-of-freedom: 3 DOFs for head motion, 7 DOFs for right arm motion, 1 DOF for hand grasp, and 3 DOFs for base locomotion. By implementing a large numbers of degrees-of-freedom, the human operator's natural motion can be reflected on the robot's motion. The right arm is equipped with a 6 DOF force/torque sensor at the wrist and is impedance controlled in order to enable stable manipulation when the fingertip is contacted to the environment. The hand grasp is also impedance controlled using strain gauge so that the hand should not crash soft objects being grasped. The head is equipped with a pair of stereo CCD cameras and stereo microphones, which supplies natural three dimensional sensation of presence to the operator.

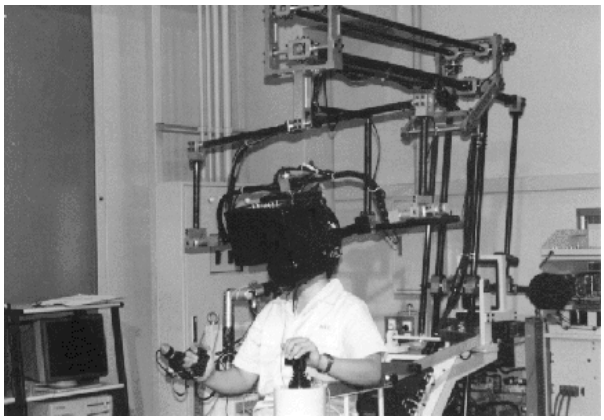

Figure 2: tele-existence master system

Figure 2 shows the master system, which measures human operator's motion in real time.

The head motion is measured by using parallel link mechanism equipped with rotary encoders (6 DOFs: 3 for translation and 3 for rotation). Thanks to this mechanism, the system can measure the translational motion and rotational motion separately, so that complicated and time consuming kinematics/inverse kinematics calculation should be avoided. The arm motion is measured by a 7 DOF exoskeletal arm, also equipped with rotary encoders. The drawback of this system is that the size is considerably big. However, by using these link mechanisms, this system can measure the operator's motion much more exactly and faster than magnetic sensors used in many virtual reality systems. Also, the output of this system is not influenced by the existence of metal objects and provides measurement result with less noise. The advantage of this system in speed and noise characteristics is important in controlling real robots, rather than generating graphics images of the virtual environment.

Each personal computer reads the human operator's motion, calculate the control output according to the impedance control algorithm in *real time*. Four personal computers are used to measure and control arm motion, hand grasp, base locomotion, and head motion, respectively. Each part of the system is separated in physical signal level so that it is not necessary for the computers to communicate with each other. Thus each computer can do its job independently, to enable high update rate of the control signal without requiring extensively high performance CPUs.

The operator wears the helmet with head mounted display (HMD), which is attached to the link mechanism. The optical alignment of the HMD, i.e., the field of view, etc., is designed equivalent to the robot cameras. To ensure the operator to recognize the objects in the displayed image to be exist at the correct position and to feel the fed back video image as *natural three dimensional space*, this equivalency is very important. It is also important in tele-existence systems that the operator can recognize his/her hand exactly in its actual position. This requirement is called *self-projection*.

The system also provides tele-existence in virtual environment. The human motion measured by the master system is sent to graphics workstations (Silicon Graphics Indigo/Indigo2) to generate the image of the virtual environment which is designed equivalent to the real environment. In this case, the projection parameters in generating computer graphics image, such as an angle of field of view and an aspect ratio, should be set carefully, such that the shape of viewing volume becomes identical to the optical alignment of the HMD.

2.3 An Example of Applied Tele-existence System

In Japan, tele-existence technology has already been applied to several sites. For example, remote observation system for volcanic activity is working at Mt. Unzen, which had a big eruption a few years ago and caused a big disaster against the foot of the mountain by its volcanic ashes, ash flow and debris flow. Human operator can observe the volcanic activity at safe location as if he/she exists at a place near the crater.

3. R^3 [R-Cube]: Real-time Remote Robotics Project

A new project, named *R-Cube*[9], has just started. Japanese government, Universities, and Companies have jointly composed a working group, studied and investigated on the concept and technological elements for the future robotics technologies. This working group will develop into a feasibility study project conducted by MITI (Ministry of International Trade and Industry) of Japan from April, 1996. This feasibility study will be taken place for two years, and if the study is successful, the project will further develop into a large national project.

R-Cube is an abbreviation for *Real-time Remote Robotics*, and its concept is based on the integration of tele-existence/virtual reality technology and networking technology. This project aims at developing human-centered, real time remote robot systems, which can work in cooperation with human being. The field of application includes supporting elderly people's living activities considering a coming society composed largely of elderly people, supporting tasks in severe environment, preventing disaster, and supporting home automation, by integrating technologies of virtual reality and robotics.

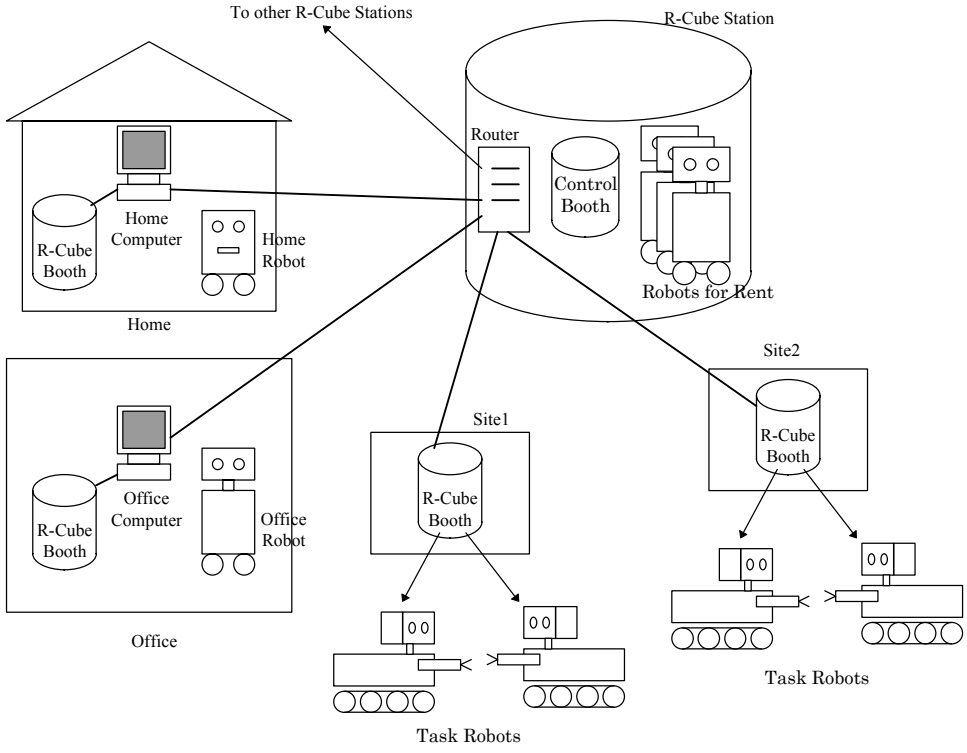

Figure 3: Concept of R-Cube Network

In the concept sketch of R-Cube, robots work not only in artificial and arranged environments such as factories, but also work in natural and/or unarranged environments, such as homes, streets, construction sites, areas suffering from disaster, mountains, seas and so on. In

other words, these robots work not only in manufacturing activities but also in people's ordinary living activities. Human operators are located in the safe cockpit and manipulate remote robots, experience the remote environment and act freely in those environment, feeling as if he or she exists in the remote environment with a sensation of presence. The concept of R-Cube network is shown in Figure 3.

According to the concept of R-Cube, robots are considered as the interface between computers and physical world. Robots are connected to the computers, and operators and robots communicate with each other through computer networks. This communication includes control command from operators to robots and sensory information (visual sensation, auditory sensation, tactile sensation, etc.) obtained by robots. Thus human being will be able to take action not only to the information stored in computers but also the "real world" through networks and robots. An example of experimental system based on the similar concept can be found in "Internet Controlled Robot" at University of South California[10].

4. Conclusion

R-Cube project has just started to develop real time remote robot system over network. Its concept can be regarded as the one that make the concept of the tele-existence more concrete. If this concept comes true, people will be able to exist all over the world, regardless of where he or she actually exists. Of course, there are a number of difficult problems to be solved. For example, how to implement "safe" robots which can work together with human beings, how to control robots autonomously when the connection between the operator and the robot is disabled, how to transmit huge amount of information to control remote robot in real time and to feedback sensory information to the human operators, and so on. However, by solving these problems step by step, the study will be expected to be successful and developing into the next stage of robotics technology.

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