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RECENT PROGRESS IN TELE-EXISTENCE AND/OR VIRTUAL REALITY

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@tansei.cc.u-tokyo.ac.jp (e-mail)

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Abstract

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. In this plenary paper, the concept of tele-existence is explained and an experimental tele-existence system is introduced, which enables a human operator to have the sensation of being in a remote real environment where a surrogate robot exists and/or virtual environment synthesized by a computer.

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 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.

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 typeof 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 to improve teleoperation by feeding back rich sensory information, which the remote robot has acquired, to the operator with a sensation of presence. 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].

In this plenary paper, the concept of tele-existence is explained, and an experimental tele-existence system is introduced, which enables a human operator to have the sensation of being in a remote real environment where a surrogate robot exists and/or virtual environment synthesized by a computer. An experimental tele-existence system in real and/or virtual environment is 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 is demonstrated experimentally.

2.Tele-Existence Master-slave System

Figure 1 shows a general view of the tele-existence master-slave manipulation system which 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.

A human operator is seen wearing a 3D audio visual display with a sensationof 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 counterbalancing mechanism, which allows the operator's unconstrained movement in a relatively wide range of operation space.

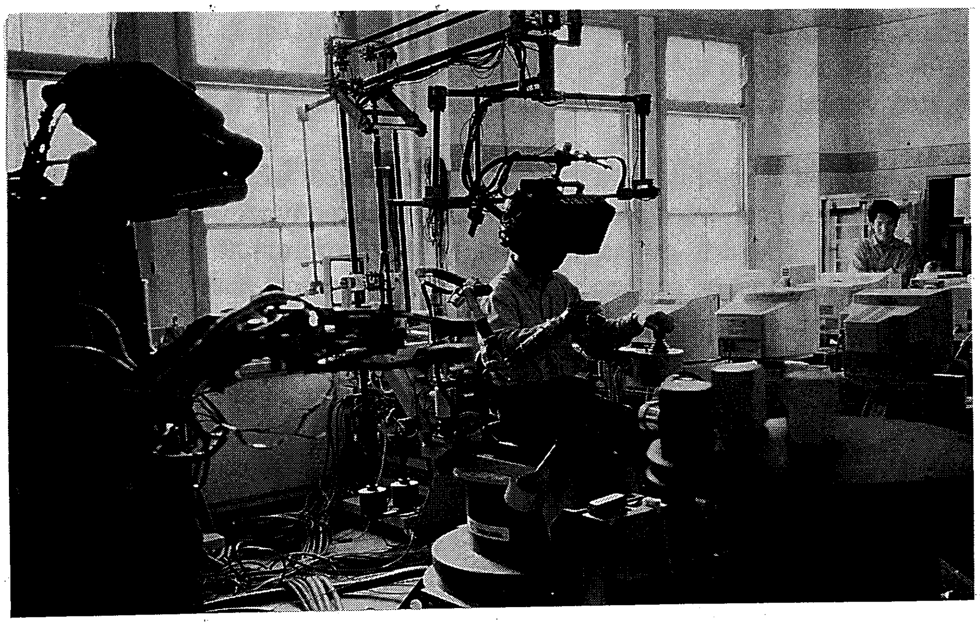


Fig.1 General View of the Tele–Existence Master–slave Manipulation System.

It also enables the display to follow the operator's head movement precisely enough to permit his/her ordinary head movement. The maximum inertial force applied to the operator remains within 5 kgf. The master arm has 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.

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 computers. There are four computers which generate the command position of the slave head movement, the arm movement, hand movement and 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 also has three degrees of freedom in the 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 themovements 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 a 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.

Figure 2 shows a general view of the anthropomorphic tele–existence slave robot under operation. 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 the sensation of presence in 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

3D virtual environment in front of his/her view, which changes according to his/her movement.

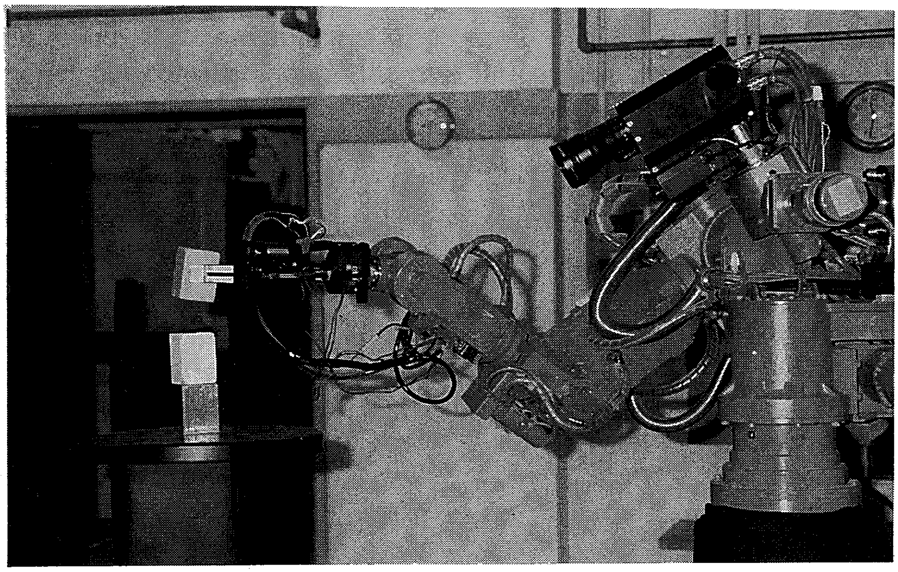


Fig.2 Tele-Existence Anthropomorphic Robot under Operation.

The stereo visual display is designed according to the developed procedurewhich assures that the 3D view will maintain the same spatial relation as by direct observation [8,19]. A pair of six-inch LCD's (H720 x V240 pixels) with a convex lens system are used. The compact arrangement of a display system suitable for the manipulation master system was made possible by arranging the two mirrors so that the LCD's can be placed on the upper side in front of the operator.

3. Experiments

Experiments which quantitatively evaluate the typical characteristics of the tele-existence master-slave system were conducted. By comparing a tele-existence master-slave system with a conventional master-slave system, efficacy of the tele-existence master-slave system was verified and the superiority of the tele-existence method was demonstrated through tracking experiments. The comparison results revealed the clear superiority of binocular vision with the natural arrangement of the head and the arm, which is the most important characteristic of tele-existence [18].

The most noticeable distinction of tele-existence and/or virtual reality from the conventional human-machine interface is that the virtual environment where the user is supposed to exist has the flowing features:
(1) The virtual environment is a 3D space which is natural to the user (Sensation of Presence); (2) it allows the user to act freely and allows the interaction to take placewith natural movement in real time (Real Time Interaction); and (3) it has a
projection of himself/herself as a virtual human or surrogate robot (Self Projection).

Thus, the most important features of tele-existence include the natural 3D vision (closely approximating direct observation), which follows the 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 is regarded as the basis of the feeling of tele–existence. This allows the operator at the control to perform tasks which require coordination of hand and eye quickly as in the case of direct operation.

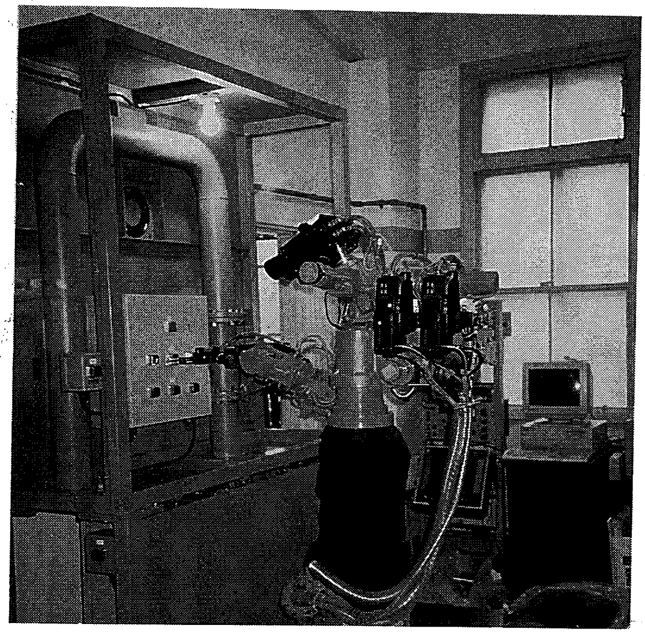


Fig.3 Tele–existence robot under operation in hazardous environment through virtual environment.

The combination of fundamental tele–existence technology with other advanced technology such as virtual environment display [20], and impedance control makes it possible to use robots in hazardous environments. Figure 3 shows that the robot works on the supposition that a pipe of a chemical plant is leaking and the plant is filled with toxic gas. The operator analyzes the situation using a virtual model environment of the plant generated by the computer according to the blueprint of the plant while the robot goes to the plant. The model environment is displayed by using the same display which is used for the tele–existence operation. When the robot arrives at the plant, the operator observes the situation through the robot's sensors as if he/she were at the spot. The operator conducts the emergency action by closing the valve and pushing the switch of the exhaust fan. The model environment can be superimposed on the real scenery. Impedance control of the slave robot's manipulator helps conduct quick manipulation tasks like closing valves and pushing switches.

4. Virtual Haptic Space

Several efforts have been made for the construction of virtual haptic space or robotic graphics [21,22]. We have proposed a method to construct a virtual haptic space driven by the same environment model of the real world as of the visual space [23]. Human limb motion is measured in real time and the subspace of the total haptic space, which is or will be in contact with the human end effector, is constructed using the haptic space display device. Its end effector is an environment shape approximation device whose shape is specially designed to approximate several shapes by changing its sides of contact. Its position and orientation is controlled by a pantographic mechanism called an active environment display. The shape of the haptic space is approximated by the environment shape approximation device, and inertia, viscosity and stiffness of the haptic space are generated by the use of the mechanical impedance controlled active environment display.

We restrict our consideration to the case that we could touch the virtual haptic space at one point, i.e. at the finger tip. We also restrict ourselves to the condition that we abandon the representation of the texture of the surface. Then the shape of an object in the virtual haptic space can be represented as a function of three dimensional point of contact (x, y, z) in the world Cartesian coordinate. One of the attributes of the virtual haptic object is which type of the fundamental shape elements the point of contact belongs to, e.g., surface, edge or vertex together with the normal vector of the surface at the point if it belongs to a surface, or the direction vector of the edge if it belongs to an edge. The virtual object's attribute which we consider other than its shape is its mechanical impedance, i.e., inertia, viscosity and stiffness for three transnational directions and three rotational directions.

Figure 4 shows how an object in the real environment is presented in the virtual haptic space. Human upper limb motion is measured by a passive master arm and the tip position and orientation of the human finger is calculated. The measured position is sent to the computer, which calculate the nearest object in the virtual haptic space. The information of the object, i.e., mechanical impedance, tangential surface and/or edge/vertex data is represented by the device which is consisted of a 6 degree of freedom impedance controlled active environment display (AED) and a shape approximation device (SAD).

When the finger is in free space, no contact is made with the SAD. However, the SAD continues to display the appropriate shape information at the point nearest to the operator's finger tip. The AED follows is controlled to locate the SAD at the appropriate position based on the measurement of the finger position/posture and the model of the virtual haptic space. When the finger tip contacts the point on the virtual object, the human finger tip contacts the SAD with appropriate mechanical impedance given by the AED. When he/she moves his/her finger, he/she feels the shape of the contact point, whether it is an edge, a vertex or a part of the surface presented using the appropriate part of the SAD. If it is an edge, he/she can find which direction the line is in the virtual haptic space. When it is a surface, surface orientation is represented.

Figure 5 shows the experimental hardware system constructed. Each object in the virtual space is represented in two ways. One is geometrical representation using polygons as is used in virtual visual space, and the other is represented using sphere, cylinder, cone, generalized cone, cube, parallelepiped, and combination of them. It is represented using the local coordinate fixed to the object in both cases. The position and orientation of the origin of the local coordinate is assigned relative to the world coordinate, and each point on the virtual model is calculated with reference to the world coordinate. Visual information and haptic information are driven by the same world model, and the visual rendering and haptic rendering are conducted in parallel. Nearest part of the virtual object to the finger is estimated by the method similar to the z–buffer method.

5. Conclusion

An experimental tele–existence system was realized which enabled a human operator to have a sensation of being in a remote real environment where a surrogate robot existed and/or a virtual environment which a computer generated.

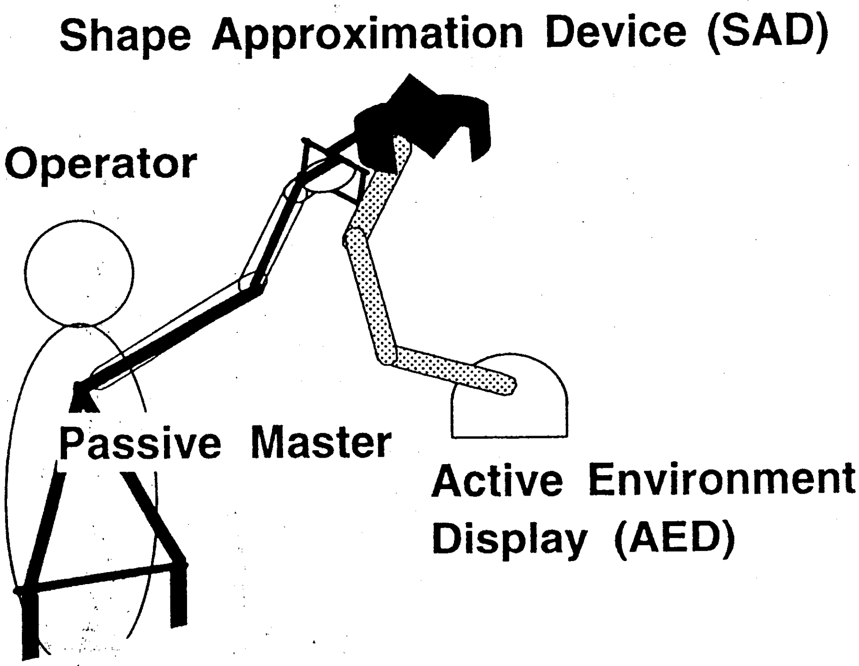
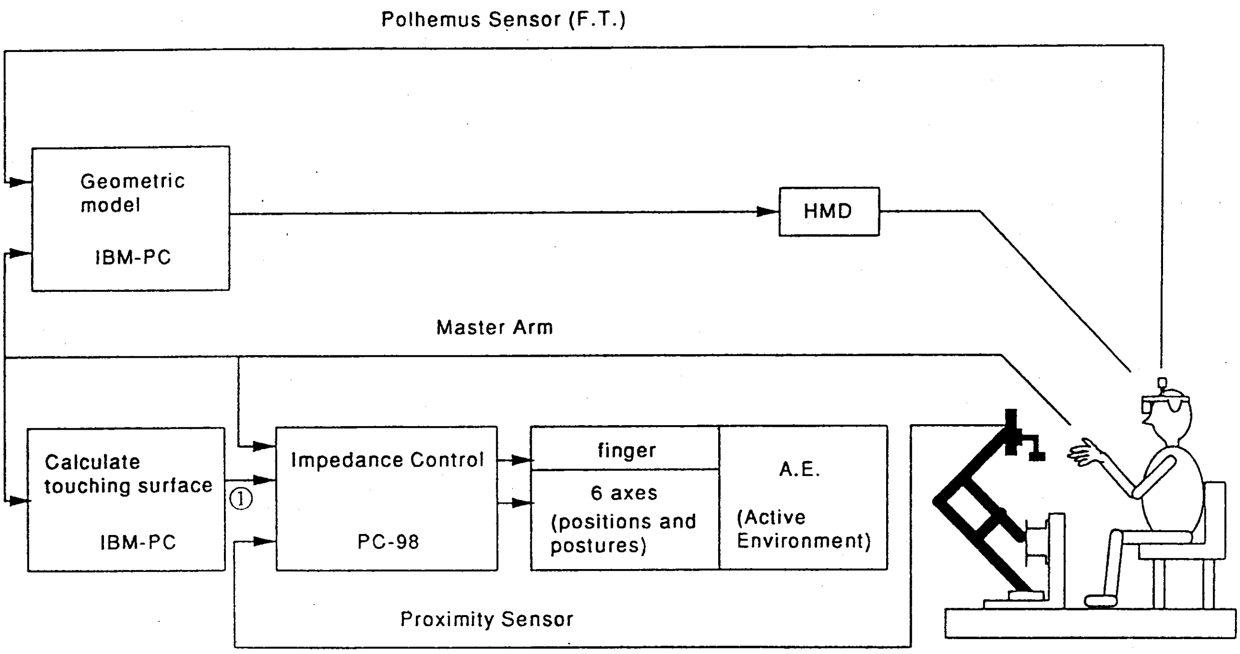


Fig.4 Conceptual Diagram of the Virtual Haptic Space Construction Method.



① • A predictive information (next motion)
• A touching point
• An information around touching surface
• An information of touching surface
(slope of surface, hardness of surface, a curved surface of a plane)

Fig.5 Block Diagram of Virtual Visual and Haptic Space Presentation System.

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