Review:

Tele-Existence

Susumu Tachi

Research Center for Advanced Science and Technology , University of Tokyo
4-6-1, Komaba, Meguro-ku, Tokyo, 153 Japan
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1. Introduction

Recently, the concept of artificial reality (virtual reality) or tele-existence has evolved, and attempts to achieve practical applications of the related technologies are actively being made.[1)-13)] For example, it has become possible to enter data representing human actions into a computer or to make the user feel as if he is entering the world of computer graphics displayed before him. Furthermore, there is a technique, which is nearing completion, that allows the operator to control robots, which are remote from him, on a real time basis by the sensation of presence. Through the use of artificial reality it may be possible to touch a product that has not yet been completed, to walk in to a house which is still in the design stage, or to manually construct matter from a vast quantity of molecules. To some people, such ideas are beyond all imagination. Tele-existence could make it possible to allocate tasks, which are traditionally done by skilled human workers in dangerous or harsh working environments, to robots. In addition, through tele-existence technology, people could go wherever they wish or experience whatever they want without having to move from their present location. Before artificial reality and/or tele-existence can be realized, it is essential to integrate and take full advantage of achievements in the following fields of applied sciences: robotics, computer engineering, three-dimensional 3D image processing, neuro-computer engineering, biomedical engineering, psychophysics, and cognitive science. All of these are based on measurement and control technology, electronics, communication, information processing, and mechatronics.

This paper will highlight several approaches to the concept of tele-existence, identify its expected applications, and present the current trend of research activities with the discussion centered on the authors research.

2.Evolution of Artificial Reality and Tele-existence

Artificial reality provides a basis for the technology which enables humans to experience events and acts in a virtual environment just as if they were in the real world. Tele-existence is similar to artificial reality, but takes a dif-

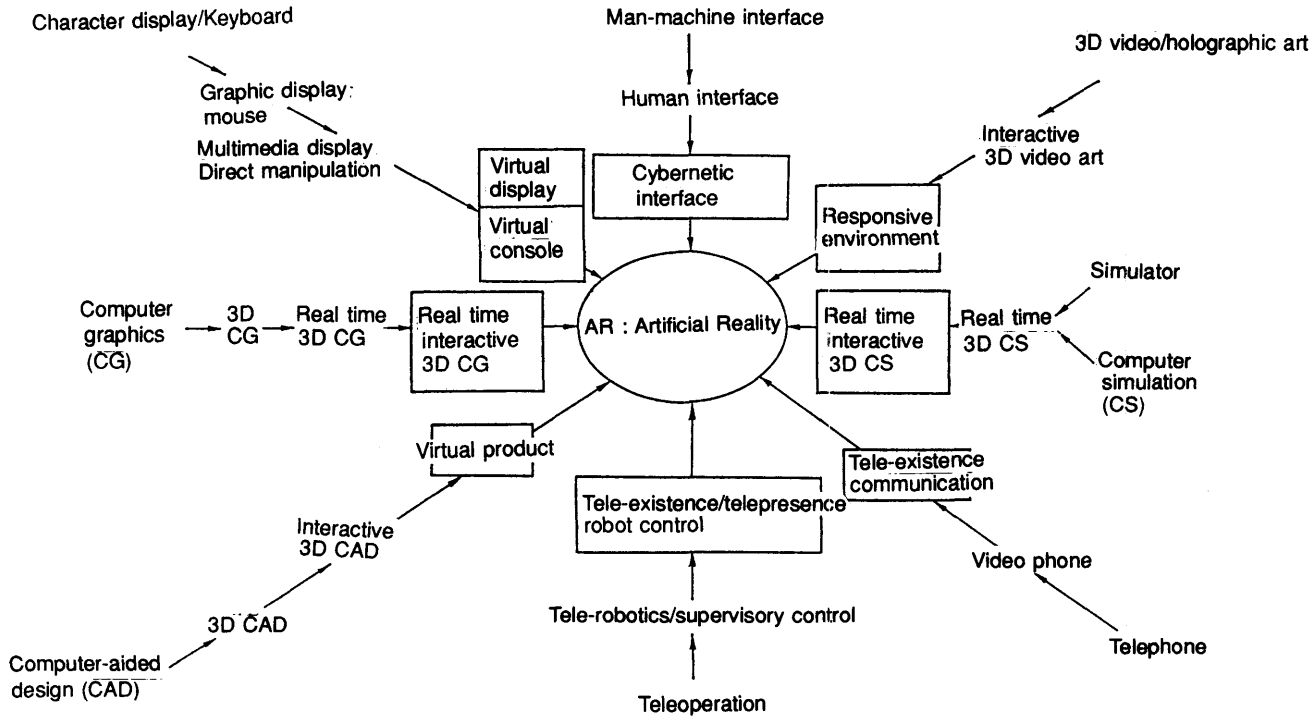

Fig. 1. Progress in artificial reality and tele-existence.

ferent 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 environment.

One of reasons for artificial reality or tele-existence attracting worldwide attention is that scientific subjects, which have been believed to belong to completely different fields of research, are likely to be united by the concept of different scientific subjects, as shown in **Fig.1.** In the case of remote-controlled robots,the development of nuclear technologies and orthotics techniques for manufacturing medical braces for handicapped people (like artificial leg) were combined after the world war II to give rise to teleoperation technology. In turn, this technology evolved into supervisory control in the 1970s, by taking in robotics, further developed into telerobotics in the 1980s. As a result, an idea of tele-existence-based remote control, which relies on tele-existence (telepresence) for a higher degree of sensation of presence on a real time basis, rapidly evolved later in the 1980s. Thus we can clearly see these fields of robotics approaching the world of artificial reality.

In the field of computer graphics (CG), the conventional 2.5-dimensional display system, in which a solid model is shaded by perspective-transformation and then displayed, has advanced to 3D display which provides the user with stereopsis or stereoscopic vision. This is now developing into an interactive 3D display system in which the image can be changed according to the user's viewpoint. This allows him to look sideways or obliquely downward/upward into the image on the display screen as in a hologram. The interactive 3D CG currently under development is in the shortest distance from the world of artificial reality.

In the field of CAD, attempts are being made to realize a design support/evaluation system based on virtual products by combining CG, tactile sensation feedback, and force sensation feedback. Virtual products could allow designers to evaluate utilization prior to manufacturing and to easily make design changes with ease if necessary. Design change data stored in computer memory is readily available to produce a "real"product if the memory is linked to CIM. The concept of artificial reality has an increasingly greater importance to industrial production because it could help produce easy-to-use products, or much more advanced products, that are expected to be in great demand in the future, and are more suited to individual user preference.

In the computer field, a more user-friendly interface is desired. In addition to the currently prevalent character display by keyboard, there are many other possible interfaces including graphical display on microcomputer, mouse input, object-oriented programming, multimedia display and 3D mouse, and input/output operations by direct manipulation. Now, it has been proposed to enter information by using virtual console and virtual display. Thus, artificial reality is likely to be incorporated in a human-computer interface.

In the communication field, the old telephone system has evolved into video phone. Tele-communications are now under intensive research, and a great demand is expected in the coming b-ISDN era for communication with a more realistic sensation of presence.

Furthermore, the simulation field is experiencing the rapid development of a real-time interactive 3D computerized simulation system which is intended for real-time operations in a near-real-experience basis.

The art and amusement industries are no exception. Artists and amusement designers are viewing artificial reality as a new art medium that could exceed existing ones with respect to the power of artistic expression.

In the conventional man-machine interface design, man has to adapt himself to the machine because man is more flexible. However, a more human friendly man-machine interface has been recently advocated. The next step is a cybernetic interface in which the machine comes unilaterally closer to man's natural sensation. This will finally attain the artificial reality. Rapid progress in computer and sensor technologies and increasing findings about human sensation, brought about by advances in human science, have made artificial reality possible. Recently, many fields of scientific research, which have advanced independently of each other, have begun to focus on the concepts of artificial reality and tele-existence and to view these concepts as key technologies of the 21st century. This encourages firms and organizations related to such fields to motivate intensive research/development programs about artificial reality and tele-existence.

Furthermore, the concepts of artificial reality and tele-existence are not simply common to the foregoing fields, the concepts themselves have a common elemental technology, as will be described in Chapter 4. Therefore, a basic technology developed in one field can be readily available to another field. This makes it more important to study all of the related fields as a single generic technology. In fact, Japanese and foreign researchers are actively studying artificial reality because they see a great importance in it.

3. Tele-existence in the Real and Virtual Worlds

Artificial reality or tele-existence may be divided into two categories: tele-existence in the real world that actually exits at a distance, and it is connected via robot to the place where the user is located; and tele-existence in the virtual world that does not actually exist but is created by computer. The former is called also remote sensation of presence or tele-reality, and the latter is virtual reality in a narrow sense.

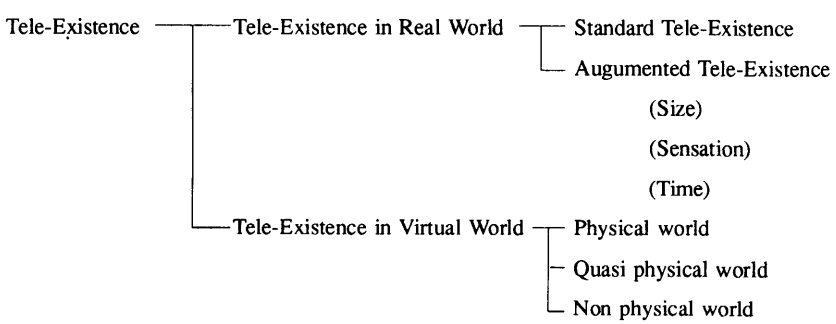

Fig. 2. Tele-existence in real and virtual worlds

However, there is usually no strict distinction between the two. **Figure 2** illustrates this classification.

3.1. Tele-existence in the Real World

The tele-existence in real world, which relies on a robot, is further divided into standard and augmented tele-existence. The former is intended to facilitate user's presence in a place, which is distant from actual location, in real time or within a negligible time delay by means of a robot. The robot is assumed to have the same external shape and sensory functions as a human. In other words, the purpose is to make it possible for the use to perform tasks in a remote environment through the help of a robot. The tasks are done with the sensation of presence and in real time. In contrast, augmented tele-existence is intended for cases in which the shape and/or sensory functions of the robot are different from a human's or the time interval is too large between events in the user's location and the remote location. Augmented tele-existence may apply to cases in which the user controls an micro-robot or controls a gigantic robot.

Although the standard tele-existence handles only signals in the frequency range among sensory channels through which the user normally detects stimuli, it is possible to lift such restrictions to augment human sensory functions. This augmentation need not be limited to sensory functions within a human's inherent senses; it can be applied to sensory functions beyond that limit. For this purpose, standard tele-existence employs such sensor information obtained through X-rays, ultra violet rays, infrared rays, micro waves, supersonic waves, and ultra-low frequencies sensed by the robot (also referred to as super-sensory information). For example, if information obtained by a robot, which scans a dark environment for an object using infrared rays, can be displayed by means of computer graphics and 3D presentation technologies, then the user would be able to see the object on the display screen as if it were bright illumination. The super-sensory information may be superimposed over the ordinary visual display image, not in ordinary superimposition but in 3D superimposition. Possible applications include the following cases: when the distance between the user and object is displayed in the form of an aerial image which is superimposed over the location of the object exists; and when only the portion of an image, which has undergone change for some reason is displayed with the added sense of presence, and the rest of the image originally visible to the user is subtracted.

Augmentation in terms of time is also possible. For applications of tele-existence to planetary exploration and other space activities, the length of communication time is an important factor for consideration. The maximum permissible time delay, which does not interfere with control in ordinary teleoperation, is believed to be about 0.1 second. Anderson et al have proposed an alternative that can keep the system stable with a time delay of up to about two seconds by converting the transmission block to a loss-free transmission line.

This makes the transmission block nearly equal to a passive element which appears to be independent of time delay. However, in a system with a time delay greater than 2 seconds, this method cannot provide proper control.

Even in such cases, augmented tele-existence may enable proper control, at least theoretically, if the following method is used with the help of the remote robot which is autonomous. The robot first scans the environment and prepares an environment model, which is sent to the remote computer system. The system displays visual, auditory, or tactile information with a sensation of presence according to the state of both the object and the user. The user performs a tasks in this virtual environment with a sensation of presence, and the essence of user's work is transmitted to the remote robot. The robot, in tele-existence mode, decodes the information or instructions for performing tasks and makes additions to or corrections in the environment model, if necessary. Any disorder produced by tasks performed strictly in accordance with the directions implies that there are defects in the model. Therefore, the robot stops operation in a safe state and then estimates an alternative model. The robot then reports its state and the new model to the user. The user performs the task over again in the virtual environment which provides sensation of presence based on the new model. Thus, augmentation in terms of time is theoretically possible. However, there still remain several unsolved problems such the vast amount of calculation required and the estimation of the model.

3.2. Tele-existence in Virtual World

A virtual world created by computer can be divided into the categories of physical world, quasi-physical world, and non-physical world. The physical world is where the same physical laws as those of our planet apply. Design support and the evaluation of virtual products must be done in the physical world. The virtual environment used for training simulators also must be set in this physical world.

In the quasi-physical world the same physical laws that governs the real world also apply; however, it contains virtual worlds such as the moon, the microscopic world where the laws of quantum mechanics rule, or a world where the principle of relativity has predominant effects over events. The concept of the quasi-physical world is useful for training/educational programs to provide trainees with experiences in a world which is utterly unknown to them.

Considering applications to leisure activities and arts, the potential applications for such fields are not necessarily limited to the physical and quasi-physical worlds. Rather, a world of imagination is often required by amusement-related industries.

The non-physical world can meet such demands. This world is technically easier to realize than the former two, although a higher artistic sense is necessary. Artistic expression by virtual reality created by the non-physical world provides a potentially new medium that, still embracing linguistic and picturized expressions but transcending them, may represent ideas, thoughts of sensibility. In this sense, the non-physical world attracts attention from artists.

3.3. Applications for Tele-existence

Research into artificial reality and tele-existence is an attempt to release the user from spatial restrictions. This is achieved not by providing information with the user in a passive state, in TV watching, but by providing an artificial, but very realistic environment where the user can feel and act as if he were there.

Based on this perspective, the goals of tele-existence may be arranged as follows:

(1) To provide substitutes for manual labor in potentially dangerous working environments such as nuclear facilities, ocean engineering, disaster-prevention, and space activities; and to apply to construction work and

mining.
(2) To apply to secondary industries, manufacturing industry, such as tele-machining as a new production support;
(3) To apply to primary industries such as agriculture (tele-farmer) and fishing;
(4) To apply to tertiary industries including cleaning, maintenance, and other services;
(5) To apply to leisure, amusement and game industries as a tele-existence trip;
(6) To apply to medical fields as in micro-surgery;
(7) To apply to communications such in communication with a sensation of presence;
(8) To apply to education, for example, an ultimate simulation including an electronic simulator;
(9) To apply virtual products to design support (CAD, IMS);
(10) To apply virtual environment to the design field, including interior design;
(11) To apply scientific visualization as a tool for scientific-engineering research;
(12) To apply display with a sensation of presence as a tool for research of the functions of humans and other living creatures;
(13) To provide a new medium that, embracing linguistic and picturized expressions and going beyond them, may express ideas and sensibility.

4. Organization of Tele-existence and its Related Problems

Figure 3 shows the organization of tele-existence. The most notable distinction of artificial reality or tele-existence is that the virtual environment where the user is supposed to exist:

(1) is a 3D space which is natural to the user; (2) allows the user to act freely; and (3) allows the interaction to take place in a natural form and in real time.

The basic technologies necessary to put tele-existence into practice include:

(i) the estimation of the user's state (including the external state represented by user movements and tone of voice and the internal state represented by brain wave and electrocardiogram) and the estimation of the human decision making process; (ii) the interaction between the robot and the natural environment and/or the interaction between the virtual human and the virtual environment; and (iii) the presentation to the user of the process described in (ii) and the results with the sensation of presence and in real time. These are what any possible applications of tele-existence should have in common. An in-depth investigation of such basic technologies is essential to the future development of tele-existence. What is characteristic of the study of tele-existence is that the achievements of one basic technology are readily available to the others.

In order to prevent artificial reality from becoming a mere application of simulation technology, it is important to connect the virtual and real environments in good harmony. The necessary technology is one of problems awaiting a solution.

Furthermore, the following concept provides a new and interesting research subject: a system of a virtual or real environment that could accept a virtual human or robot of another tele-existence system and allow them to exist with the original virtual human or robot. This will give rise to new interaction between virtual humans or robots of the two

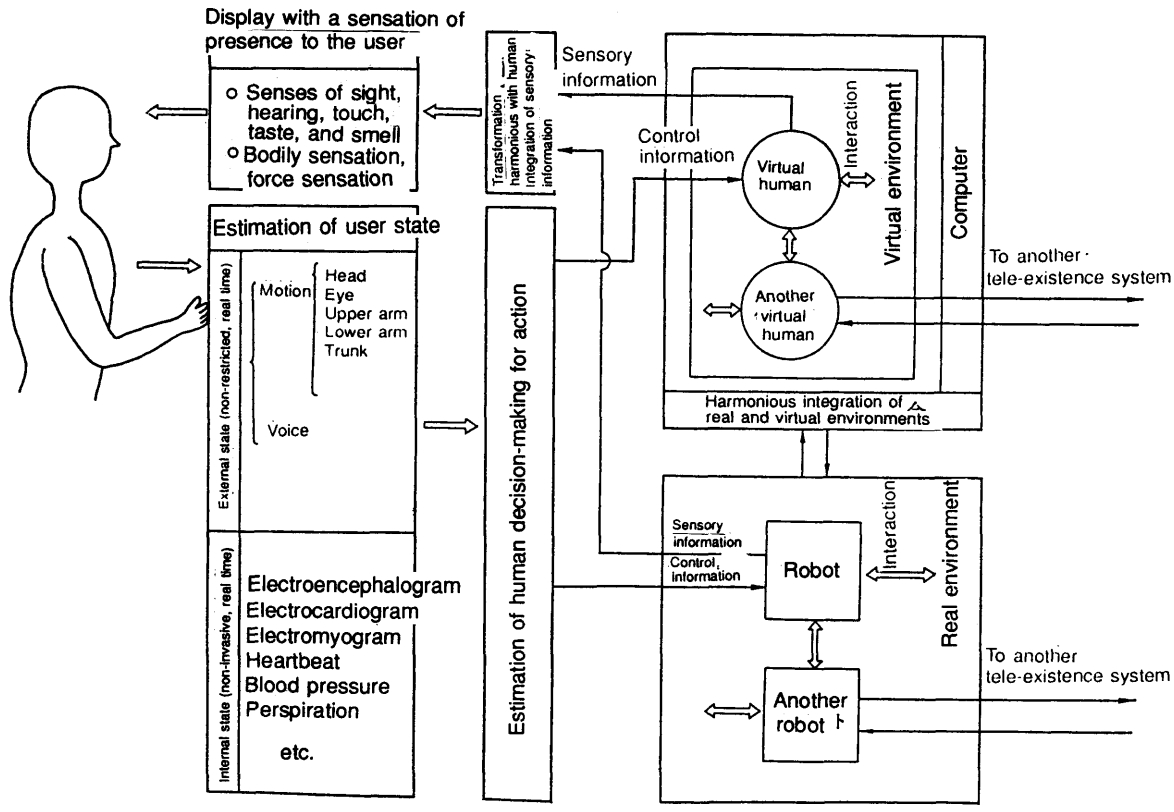

Fig. 3. Organization of tele-existence system.

or more systems, in addition to the existing interaction between the environment and robot.

5. Present State of Research and Development of Tele-existence

Because a detailed description of tele-existence in virtual world is provided in the other commentary, the author will present tele-existence in the real world with the discussions focused on the author's work.

A series of intensive research on viable design procedures of visual display system[3] has been conducted with good results. For a visual display system to be regarded as an ideal system with a sensation of presence, it must allow the user the same "clues," or means to act on it, that he has in actual 3D space through direct-viewing. If a 3D display system which has the same clues as a direct-viewing system such as visual convergence, parallax, magnitude of image, and eye lens accomodation, is given an additional function which enables images on the display screen to change according to the movement of the viewer, then it is defined as an active 3D display system. A tele-existence system requires this type of 3D display.

For the ideal visual display system, two cameras are installed apart from each other the same distance as between a human's eyes. The mechanism equipped with the pair of cameras is controlled by the neck motions of the user. First, head movement is measured. According to the results, the angles of convergence for the cameras and display image (θn and θr) are controlled so that $\theta n = \theta r$. At the same time, the distance to the object, Xr, is determined, which enables the cameras to focus their lenses on the object. In the display unit, the lens system mounted in front of the CRT is controlled so that Xn = Xr, for the position of the virtual image, and In = Ir, for the magnitude of the image.

There are three parameters which govern human visual perception of space. In monochrome, surrounding him: (a) the contraction/relaxation of ciliary muscle for adjusting the thickness of the crystalline lens; (b) the magnitude of the image on the retina; and (c) the angles of convergence of the eyes. In an ideal system, the values of these parameters should be equal to their respective values for ordinary direct viewing. Accordingly, the ideal system can provide the user with the same visual perception as by direct viewing.

Next, the author discusses how to simplify such an ideal system. Taking the characteristics of the human optic function into consideration, process (a) can be executed in a simpler manner. Even if the crystalline lens is set to operate only for a fixed distance to an object of, 20cm as an example, its images on the two retinas are naturally fused to form a single image of the object for the convergence range from 10 to 50cm. In other words, with the focal length fixed to 1m, the optical mechanism can accommodate the convergence range from 20cm to infinity. Therefore, even if the distance Xn is taken as 1m, the sensation of presence is maintained.[3] If the distance displayed, Xn, is kept constant, then the number of variables that need to be controlled is reduced to two, the magnitude of image and the angles of convergence of the eyes. This would make it possible to construct a simpler tele-existence system.[3] Such a system could re-create the same space around the user as that where robot is operating by using a wavefront re-creation system. Accordingly, there is no need to control the robot's eyes by measuring the movement of the eyes of the user.

Remote-controlled robot systems have been manufactured as an experiment and tested to verify the basic concept of tele-existence.

A tele-existence system intended for a manipulative task is shown in **Fig.4.** Tele-existence master equipment, as shown in **Fig.5**, was combined with a human-shaped slave robot, which was constructed so that its shape and degrees of freedom were similar to those of a human, and was put to a task test. The results were compared to the abilities of a conventional two-dimensional (2D) display system, providing the superiority of the tele-existence system over the 2D system.[6] **Figure 6** shows another tele-existence system which experimentally presents a bouquet to a girl. The success of the bouquet presentation ceremony has proved that any user can operate a tele-existence system without special training to coordinate the eyes and hands of the robot. It also suggests that such a system may coexist with human beings by serving useful functions.

A mobile tele-existence system intended for carrying such a manipulator is currently under study. A running test conducted on a mobile system on the premises of a laboratory has shown that the user can control a mobile tele-existence system as if driving his car, even in an environment with obstacles.

The study of tele-presence is being conducted on the Naval Ocean Systems Center (NOSC) tele-operated vehicle and on the NOSC tele-operated robot at NOSC in the United States.[5] Furthermore, NASA has launched a research/development program of a tele-presence geologist aimed at identifying its application to activities on Mars.

6. Conclusion

There is an increasing interest in tele-existence involving artificial reality by researchers of both Japan and Overseas countries. As our original technology which evolved from the Mechanical Engineering Laboratory of the Agency of Industrial Science and Technology, tele-existence has played a major role in the large national project entitled Advanced Robot Technology (Research and Development of Task Robot for Potentially Dangerous Working Environments). 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.

These tests have also helped to establish design procedures for basic systems. In addition, the results of the author's work have been incorporated in an experimental system intended for marine tasks, which is almost on the verge of practical application.

M.L. Minsky, of the MIT Media Lab, calls this idea tele-presence, which is recently a focus of study by NASA. In the U.S., the concept of artificial reality and virtual reality has also come into being, and efforts are being actively made toward its research and development as well as its application. In this context, Japanese researchers have spent approximately ten years in nourishing its original idea and basic technology. It is now widely regarded as one of the key technologies which was born in Japan and is expected to play a significant role in the 21st century.

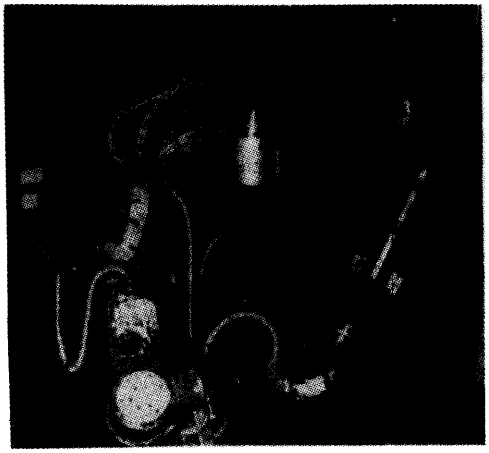

Fig. 4. Tele-existence slave robot.

Fig. 5. Tele-existence master equipment.

Fig. 6. Interractiove works between man and machine with Tele-Existance environment.

The author believes that Japan should continue to claim the originality of its idea and technology to avoid another incidence of Japan-U.S. friction that might arise from a misunderstanding. Looking back to the first principles of tele-existence reminds us that it is aimed at a human. This enables the robot to perform task that only humans can do, unites the ability of the robot with the user on a cybernetic basis, and finally substitutes the robot for the user in performing tasks that even man cannot do. Therefore, the tele-existence system is expected to be one of leading alternatives to human laborers in doing dirty or dangerous tasks which they dislike.

Tele-existence seems to represent a technology which has been long yearned by people who believed they could display their potential power to the maximum or become a super man. Tele-existence technology will make it possible for man to go through experiences which had been deemed impossible. In addition, it can evolve into something like an artificial experience culture. While containing conventional expressions by character, picturized expression and musical expression, this culture transcends them and develops into a new medium for expressing thoughts and sensibility. In the United States, there is a plan to establish a consortium administered chiefly by the University of Washington, the publication of Presence. (a new scientific journal from MIT Press), and a virtual network plan connecting MIT, VPL and the University of North Carolina. This consortium is giving impetus to research and development activities.

In Japan, the Image Laboratory has been established, and the Study Committee of Artificial Reality and Tele-existence has been inaugurated, attracting increasingly strong attention from the government and related industries. With this background, the author expects that tele-existence and artificial reality will find applications in a variety of fields.

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