Measurement and Control in Virtual Reality and Tele-Existence

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Abstract

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. 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. He or she can tele-exist in the transmitted real world where the robot exists or in a synthesized world which a computer has generated. It is possible to tele-exist in a combined environment of transmitted and synthesized. Thus tele-existence and virtual reality are essentially the same technology expressed in different manners. In this paper, present status of virtual reality and/or tele-existence as tools for communication, control, creation, entertainment, experience, and elucidation (3C's and 3E's) is reported with special emphasis on measurement and control.

Keywords: Virtual Reality, Artificial Reality, Tele-Existence, Telepresence

1. Introduction

"Virtual" is defined as "existing in effect or essence though not in actual fact or form," and virtual image is an example of its use. Virtual 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 virtually the same concept as virtual reality, but takes a different 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 space. The concept of the tele-existence is proposed by the author in 1980 and plays the role of the fundamental principle of the eight year National Large Scale Project of "Advanced Robot Technology in Hazardous Environment" which started in 1983 together with the concept of the Third Generation Robotics.

One of the reasons for virtual reality and/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 unified by the concept of virtual reality as shown in Fig.1. Several books and papers are published from variety of fields, including the ancestral papers of back in 1960's ((1-6), [1-21]).

In the case of robotics and teleoperation, the development of nuclear technologies and prosthesis techniques for disabled people like artificial limbs were combined after the world war II to give rise to teleoperation and robotics technology. In turn, this technology evolved into supervisory control in the 1970's, by taking in computer sciences, further developed into telerobotics in the 1980's.

As a sublation of exoskeleton human amplifier and supervisory control, an idea of tele-existence-based remote control, which relies on tele-existence for a higher degree of sensation of presence on a real time basis, rapidly evolved early in the 1980's. Thus we can clearly see these field of robotics and teleoperation approaching the field of virtual reality.

In the field of computer graphics (CG), the conventional 2.5 dimensional display system, in which solid model is perspective-transformed, Gouraud shaded and then displayed, has advanced to 3D display which provides the user with stereopsis or stereoscopic vision. This is now developing into interactive 3D display system in which the image can be changed according to the user's viewpoint. This allows him/her 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 to the designer and/or potential users. Virtual products could allow definers to evaluate utilization prior to manufacturing and easily make design changes with ease if necessary. Design change data stored in computer data base is readily

available to produce a "real" product if the database is linked to CIM. The concept of virtual reality has an increasingly greater importance to industrial production because it could help 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 commanded by keyboard, there are many other possible interfaces including graphic display on microcomputers, mouse input, object-oriented programming, multi-media display, 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.

Further more, the simulation field is expecting the rapid development of 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 exceptions. 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, which is named human interface. 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 mechanism, brought about by advances in human sciences, have made artificial reality possible. Recently, many fields of scientific research, which have advanced independently of each other, have begun to focus on the concept of virtual reality and tele-existence and to view these concepts as key technologies of the 21st century. This encourages industries and institutions related to such fields to motivate intensive research and development programs about virtual reality and tele-existence.

Furthermore, the concepts of virtual reality and tele-existence are not simply common to the foregoing fields, the concepts themselves have common elemental technologies as will be described later. 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, researchers are actively studying virtual reality because they see a great importance in it as a new discipline of science and technology.

2. Tele-Existence in the Real and Virtual Worlds

Virtual reality or tele-existence may be divided into two categories: tele-existence in the real world that actually exists at a distance, and 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 crated by computer. The former can be called "Transmitted Reality," while the latter is "Synthesized Reality." The synthesized reality can be classified into two, i.e., virtual environment as a model of the real world and virtual environment of an imaginary world. Combination of transmitted reality and synthesized reality is also possible and has great importance in application. Thus it might be called virtual existence to clarify the importance of harmonic combination of real and virtual worlds. Figure 2 shows the classification of the virtual reality.

3. Applications of Tele-Existence and Virtual Reality

Research into virtual 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 providing an artificial but very realistic virtual environment where user can feel and act as if he/she were virtually there.

Based on this perspective, the application of virtual reality and tele-existence includes the following:

Control:

(1) To provide substitutions 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 industries such as tele-machining as a new production support;

(3) To apply to primary industries such as agriculture (tele-farmer) and fishing (tele-fisher);

(4) To apply to tertiary industries including cleaning, maintenance, and other services;

(6) To apply to leisure, amusement and game industries as a tele-existence travel;

(7) To apply to medical fields as in micro surgery and home health care;

Communication:

(8) To apply to communications such as in communication with a sensation of presence;

Creation:

(9) To apply virtual environment to the design field, including virtual products and interior design;

Experience:

(10) To apply to education, for example, an ultimate simulation including an electronic experience simulator;

Elucidation:

(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;

Entertainment:

(13) To provide a new medium that, embracing linguistic and picturized expressions and going beyond them, may express human ideas and concepts.

On the whole, virtual reality and tele-existence will be the tools for 3Cs and 3Es, i.e., communication, control, creation, experience, elucidation, and entertainment.

4. Organization of Tele-Existence System

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

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 electroencephalogram, myoelectric signal, etc.) 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; (iii) the presentation to the user of the process described in (ii) and the results with the sensation of presence 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 virtual 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 for this is one of the 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 or more systems, in addition to the existing interaction between the environment and robot.

5. Research and Development of Tele-Existence

The author has been working for the realization of the concept and application to the robotics since 1980 [3,5,8,15,16]. Figure 4 and Fig. 5 show general views of the tele-existence master slave system for robotic application. The tele-existence master slave system 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 and a locomotion mechanism. The operator's head movement, right arm movement, right hand movement and other auxiliary motion including 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 to the four computers, respectively. Each computer generates the command position of the slave head movement, the arm movement, hand movement or locomotion of the slave robot. The servo controller controls the movement of the slave anthropomorphic robot. 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.

A specially designed 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 sensation of presence of 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 sees the three dimensional virtual environment in front of his view, which changes according to his movement.

The slave robot has a locomotion mechanism and a hand mechanism. The robot has also a three degree of freedom 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 robot's structural dimensions are set very close to those of a human.The weight of the robot is 60 kg, and the arm can carry a 1 kg load at the maximum speed of 3 m/s. The precision of position control of the wrist is ± 1 mm. 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 the movements of a human, while the speed is set to match the moderate speed of human motion (3 m/s at the wrist position).

A human operator wears the 3D display with a sensation of 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 counter balancing mechanism with a relatively wide range of operation. It also enables the display to follow the operator's head movement precisely enough to ensure his/her ordinary head movement. Maximum measured

inertial force is within 5 kgf. The master arm consists of 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.

Stereo visual display is designed according to the developed procedure which assures that the three dimensional view will maintain the same spatial relation as by direct observation. Six inch LCDs (H720 x V240 pixcells) are used. Two mirrors are arranged so that the LCDs can be placed on the upper side in front of the operator. These made possible the compact arrangement of the display system suitable for the manipulation master system.

With using the same system, tele-existence in the computer generated environment is attained. Measured human movements (head arm, hand and auxiliary) are also applied to two computers which are in charge of the generation of virtual environment (Silicon Graphics Elan) through a 386 based dedicated computer for measurement.

The graphics computers generate two shaded graphic images which are applied to the 3D visual display. The measured pieces of information are used to change the viewing angle, orientation and location of the virtual human in the virtual environment in real time. Thus the operator sees the three dimensional virtual environment in front of his/her view, which changes according to his/her movement. He or she can interact with either the real environment where the robot exists or the virtual environment which the computer generates.

6. Conclusion

There is an increasing interest in tele-existence involving virtual reality not only academic sectors but also in industries. 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 a virtual experience culture. While containing conversational expressions by character, picturized expression and musical expression, this culture transcends them and develops into a new medium for expressing thoughts and sensibility.

Measurement and control are expected to play an important role in the development of virtual reality and tele-existence.

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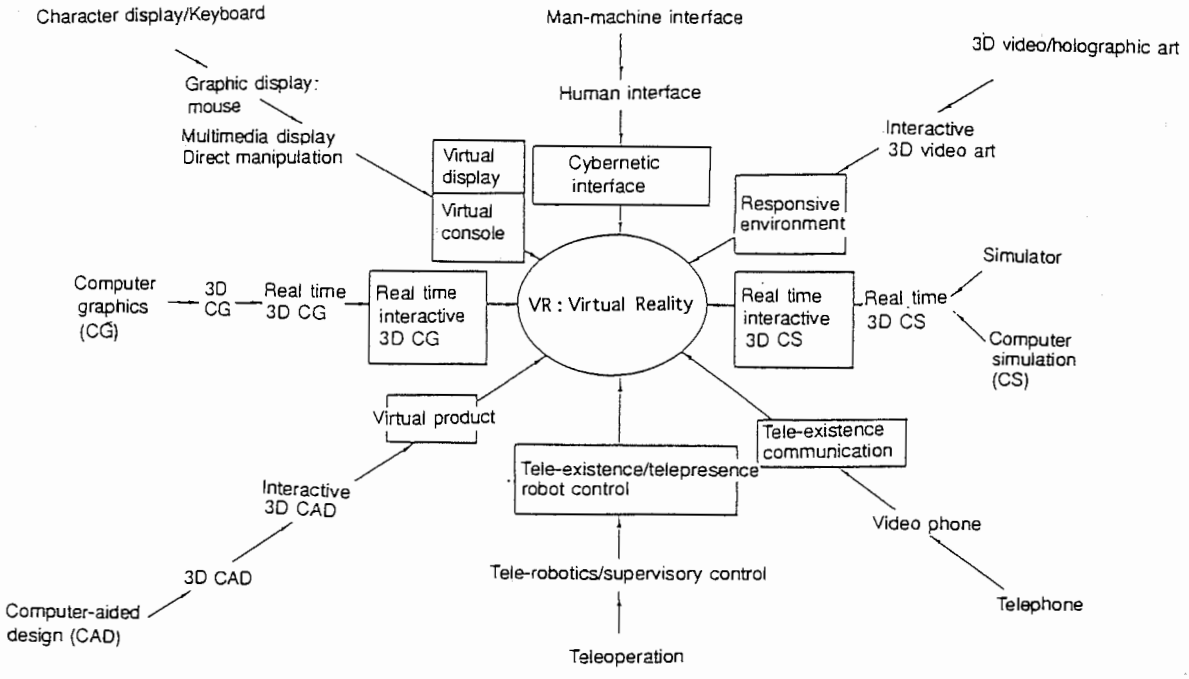

Fig.1 Present Status of Virtual Reality

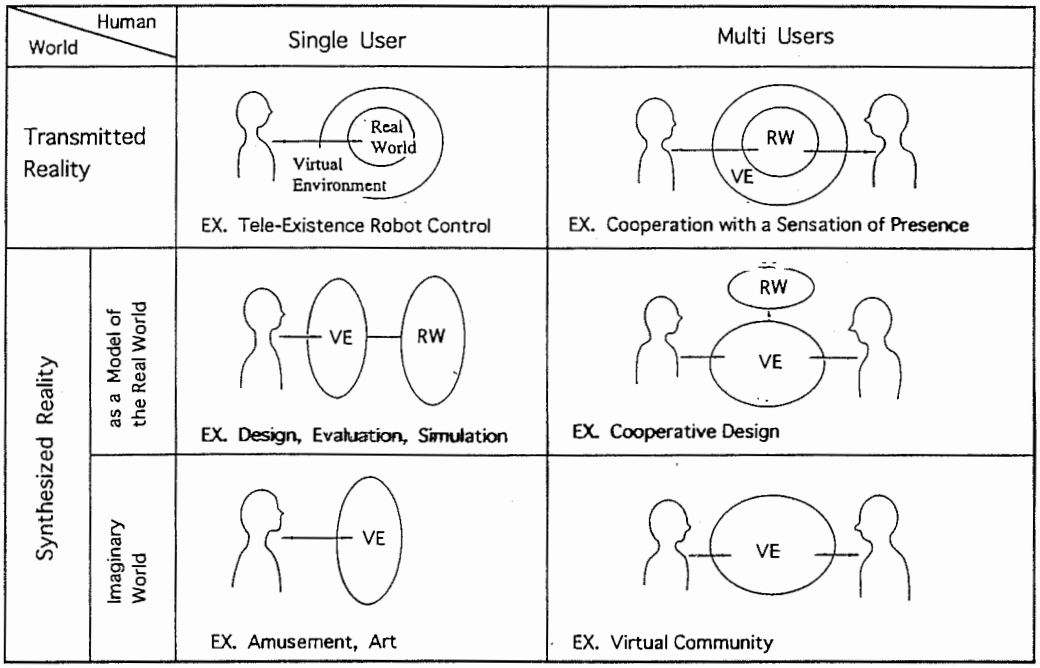

Fig.2 Classification of Virtual Reality

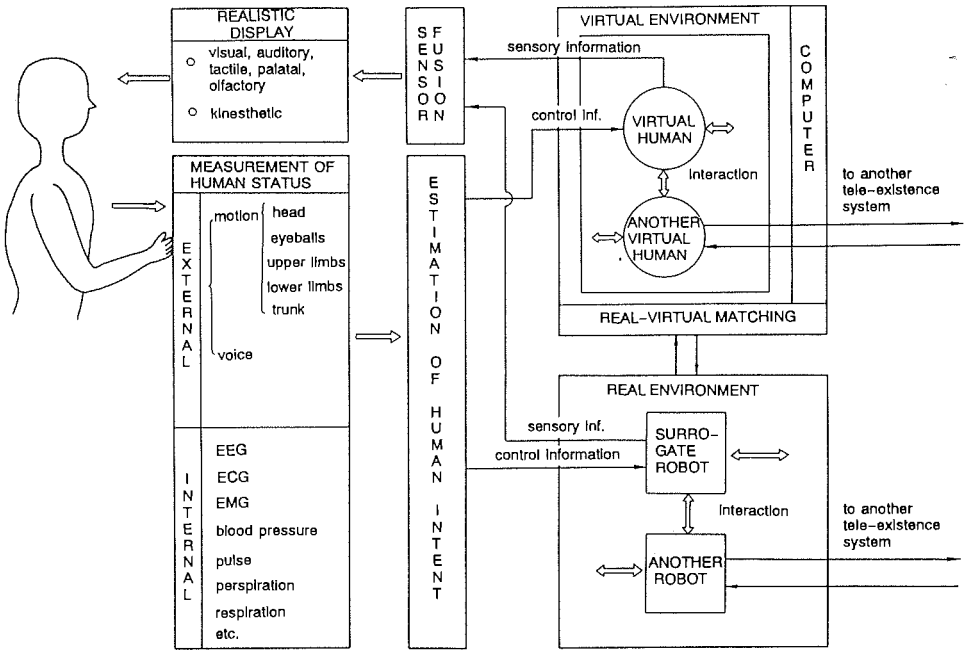

Fig.3 Organization of Virtual Existence System

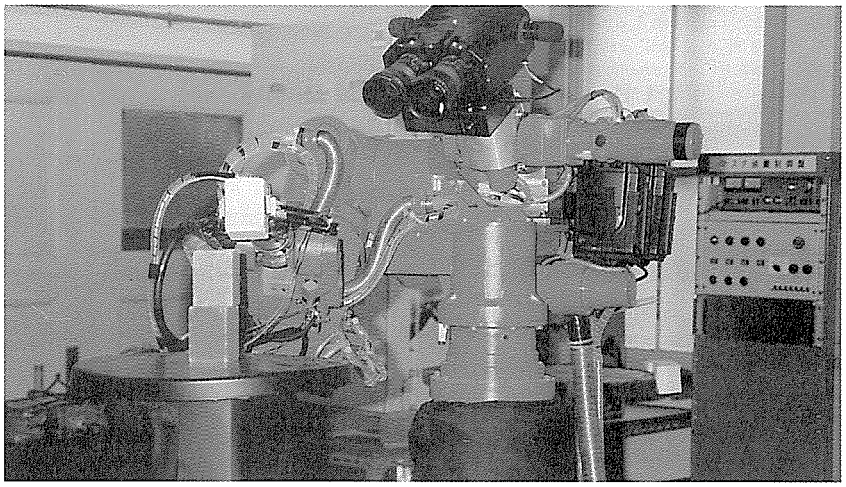

Fig.4 Tele-Existence Robot Anthropomorphic (TERA)

Fig.5 Tele-Existence Master Slave System