

Chapter 1

Virtual Reality and Telexistence

According to the American Heritage Dictionary, “virtual” is defined as existing in effect or in essence though not in actual fact or form. Thus, virtual reality is an entity which contains the essence of reality and is effectively real. It can provide a basis for technology which enables humans to experience events and act in a computer-synthesized environment just as if they were in a real environment. Although telexistence (tel-existence) is essentially the same concept as virtual reality, it takes a different point of view. It represents a new concept, which frees humans from the restrictions of time and space and allows them to be effectively present in places other than their current location as well as to interact with those remote environments, which may be real, computer-synthesized, or a combination of both. Thus, virtual reality and telexistence are essentially the same concept expressed in a different manner. Usually, virtual reality is used for computer-synthesized worlds, while telexistence is used for the real world. However, both concepts can be regarded as tools for communication, control, and creation (the 3Cs) or entertainment, experience/education, and elucidation (the 3Es).

1.1. What is Telexistence and What is Virtual Reality

The concept of telexistence was proposed by the author in 1980 and played the role of the fundamental principle behind the eight-year national large-scale project entitled “Advanced Robot Technology in Hazardous Environments,” which was established in 1983 together with the concept of third-generation robotics (Tachi *et al.*, 1980, 1981; Tachi and Abe, 1982; Tachi and Komoriya, 1982).

Telexistence is a concept that refers to the technology, which enables a human to have a real-time sensation of being at a place other than his or her current location. He or she can telexist in a transmitted real world where the robot is located, or in a computer-generated world. Incidentally, telexistence in a computer-generated world is virtual reality in a narrow sense. It is possible to telexist simultaneously in a combination of transmitted and synthesized environments.

Virtual reality in a broad sense is a technology, which invokes a sensation of being present in a realistic virtual environment other than the actual current environment, and provides the means of interacting with the virtual environment in real time (Mann, 1965; Sutherland, 1968; Schmandt, 1983; Brooks, 1986; Fisher *et al.*, 1986). Thus, telexistence and virtual reality are essentially the same technology expressed in different ways.

It was Rheingold (1991) who defined computers as “tools for thoughts.” In this sense, the author tends to define virtual reality and/or telexistence as “tools for creation.” Furthermore, virtual reality and telexistence are not only tools for creation, but also contain within themselves the possibility of becoming tools, which are useful for various human activities which can be referred to as “human tools for the 3Cs and the 3Es.” As mentioned above, the three Cs stand for control, communication, and creation, while the three Es represent experience/education, elucidation, and entertainment.

1.2. Telexistence in the Real World and in Virtual Worlds

Telexistence can be divided into two categories: telexistence in the real world, where the environment actually exists at a certain remote place and is connected via a robot to the place where the user is located, and telexistence in a virtual world which does not actually exist but is created by a computer (Fig. 1.1).

The former can be referred to as “transmitted reality,” and the latter as “synthesized reality.” Synthesized reality can be further classified into two categories, namely virtual environment as a model of the real world and virtual environment as a model of an imaginary world.

Combinations of transmitted reality and synthesized reality are also possible, and such mixed environments are of great practical importance. Thus, this can be referred to as virtual existence in order to clarify the importance of the harmonic combination of real and virtual worlds.

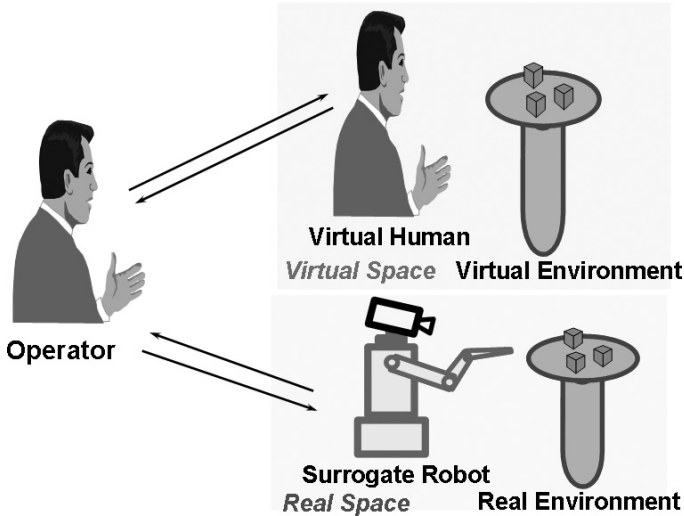


Fig. 1.1. Telexistence in a real environment and telexistence in a virtual environment.

1.2.1. Telexistence in the Real World

Telexistence in the real world, which relies on robots, is further divided into standard and augmented telexistence. The former is intended to facilitate the user's presence in a place which is distant from his or her actual location in real time or with 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 user to perform tasks in a remote environment with the help of a robot. The tasks are performed with the sensation of presence and in real time.

In contrast, augmented telexistence is intended for cases in which the shape/size and/or the sensory functions of the robot are different from those of a human, or the time delay between events in the user's location and the remote location is too long. For instance, augmented telexistence can be applied in cases in which the user controls a micro-sized or a very large robot.

Although standard telexistence handles only signals in the frequency range of the sensory channels through which the user normally detects stimuli, it is possible to lift such restrictions in order to augment the 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, augmented telexistence employs sensory information obtained through X-rays, ultraviolet rays, infrared rays, microwave radiation, supersonic waves, and ultralow frequency waves 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 by using infrared rays can be displayed by means of computer graphics (CG) and 3D presentation technologies, then the user would be able to see the object on the display screen as if it were brightly illuminated.

Super-sensory information can also be superimposed over the ordinary visual display image through 3D superimposition rather than ordinary 2D superimposition. The possible applications of this functionality include the cases when the distance between the user and the object is displayed in the form of an aerial image, which is superimposed over the location of the object, and when only the portion of an image which has undergone changes for one reason or another is displayed with the added sensation of presence, and the rest of the image originally visible to the user is subtracted.

Augmentation in terms of time is also possible. In the case of the application of telexistence to planetary exploration and other space activities, the delay in the 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 s. Anderson and Spong (1989) have proposed an alternative which can keep the system stable with a time delay of up to about 2 s by converting the transmission block into a lossless transmission line.

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

Even in such cases, augmented telexistence can enable proper control, at least theoretically, if the following method is used with the help of an autonomous remote robot. 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 by taking into account the state of both the object and the user. The user performs tasks in this virtual environment with a sensation of presence, and the essence of the user's work is transmitted to the remote robot.

A robot operating in telexistence mode decodes the information or the instructions for performing tasks and makes additions or applies corrections to the environment model, if necessary. Any discrepancies produced by tasks performed strictly in accordance with the directions imply that there are defects in the model. Therefore, the robot stops operation upon reaching a safe state and then estimates an alternative model. The robot then reports its state and the new model to the user. The user then performs the task again in the virtual environment, which provides a sensation of presence, based on the new model.

Thus, augmentation with respect to time is theoretically possible, although there still remain several unsolved problems, such as the vast number of calculations required and the difficulties associated with the estimation of the model.

1.2.2. *Telexistence in Virtual Worlds*

Virtual worlds created by a computer can be divided into three categories: the physical world, quasi-physical worlds, and non-physical worlds.

In the physical world, the same physical laws apply as those on our planet. Design support and evaluation of virtual products must be performed in the physical world. The virtual environment used for training simulators must also be set in the physical world.

In quasi-physical worlds, the same kinds of physical laws governing the real world apply. However, such worlds can comprise virtual environments corresponding to actual environments such as the Moon, the microscopic world, where the laws of quantum mechanics apply, or a world where the principle of relativity governs the events. The concept of a quasi-physical world is useful for training or educational programs, which provide trainees with experience 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, imaginary worlds are often required in entertainment industries.

Non-physical worlds can meet such demands. Such worlds are technically easier to realize than the former two, although higher artistic sense is often necessary. Artistic expression through virtual reality created in a non-physical world provides a potentially new medium, which embraces linguistic and pictorial means of expression while transcending them at the

same time, and can represent ideas and thoughts of sensibility. In this sense, non-physical worlds attract the attention of artists.

1.2.3. *Applications of Telexistence*

Research conducted on virtual reality and telexistence represents an attempt to release humans from spatial restrictions and time constraints.

Based on this perspective, the possible applications of telexistence can be outlined as follows:

- (1) Providing substitutes for manual labor in potentially dangerous working environments, such as nuclear facilities, ocean engineering, disaster prevention, and space activities, as well as application in construction work and mining.
- (2) Application in secondary industries, i.e. manufacturing industries, using telemachining systems as new production support tools.
- (3) Application in primary industries, such as agriculture (telefarmers) and fishing (telefishermen).
- (4) Application in tertiary industries including cleaning, maintenance, and other services.
- (5) Application in leisure, amusement, and game industries in the form of telexistence surrogate travel.
- (6) Application in medical fields, such as microsurgery, telesurgery, and telemedicine.
- (7) Application in communication industries, such as communication with a sensation of presence.
- (8) Application in the education industry, for example, using experience simulators.
- (9) Application in support tools (CAD (computer aided design), IMS (intelligent manufacturing system)) for designing virtual products.
- (10) Application in the field of design, including interior design, for developing virtual environments.
- (11) Application in scientific-engineering research using virtual scientific visualization as a tool.
- (12) Application in research on the behavior of humans and other organisms by using displays providing a sensation of presence.
- (13) Providing a new medium of communication which, by embracing linguistic and pictorial expressions and going beyond them, can be used for expressing ideas and sensibility.

1.3. Organization of Telexistence and/or Virtual Reality Systems

The most notable characteristics of virtual reality and/or telexistence is that virtual environments

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

Therefore, the three essential features of virtual reality and/or telexistence are as follows (Fig. 1.2):

- (1) providing a 3D space which is natural to the user (3D life-size environment),
- (2) allowing the user to act freely and allowing the interaction to take place in a natural form and in real time (real-time interaction), and
- (3) providing the user with a realistic projection of himself/herself as a virtual human or a surrogate robot (self projection).

Figure 1.3 shows how telexistence systems are organized. The basic technologies necessary to put telexistence into practice include: (i) the estimation of the user's state (including the external state represented by user movements and tone of voice, as well as the internal state represented by electroencephalograms and electrocardiograms) and the evaluation of the human decision making process; (ii) the interaction between the robot

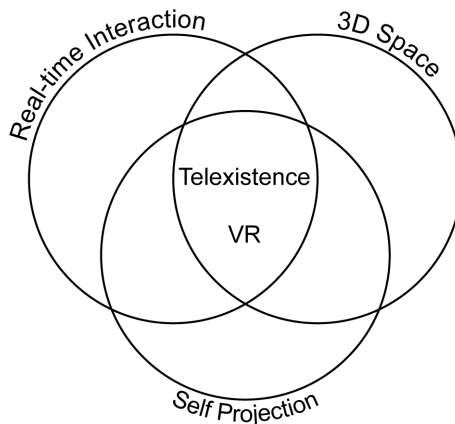


Fig. 1.2. The three fundamental elements of virtual reality and/or telexistence.

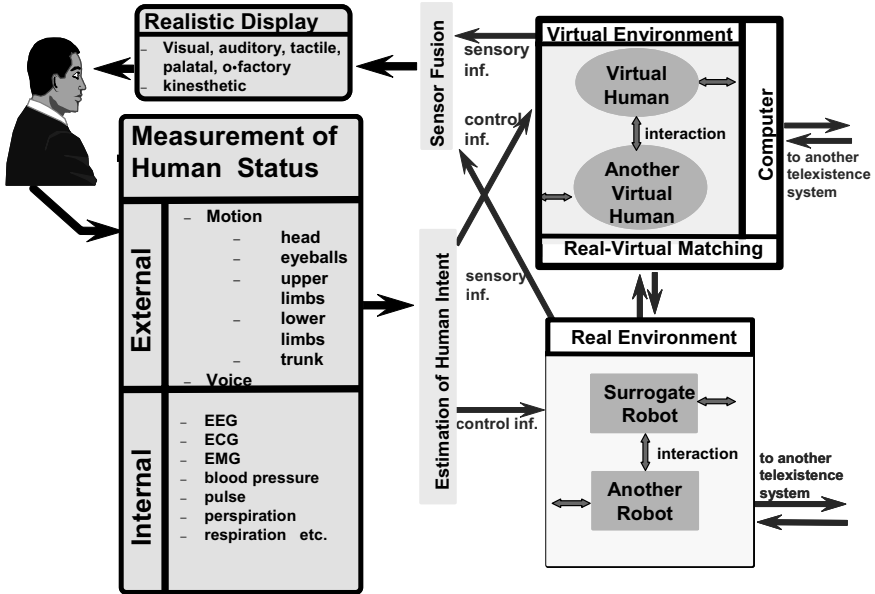


Fig. 1.3. Organization of a telexistence system.

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 its results with the sensation of presence in real time. These are the basic technologies that all the telexistence systems should have in common. An in-depth investigation of such basic technologies is essential to the future development of telexistence. What is characteristic of the study of telexistence 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 development of technology necessary for accomplishing this task 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, which can accept a virtual human or a robot of another telexistence system, presenting them together with the original virtual human or robot. This can give rise to new interactions between virtual humans or robots from two or more systems, in addition to the existing interaction between robots and their environments.

| | | | | | |
|---|---------------------|---|--|---|--------------------------|
| Roles as Human Tools | | 3C's | | 3E's | |
| | | control communication creation | | elucidation | experience/ education |
| Space Characteristics | | Telexistence Robot Control Telemedicine Teleconference with a sensation of existence | | Experience using Telexistence Telexistence Adventure | |
| Transmitted Reality Including Augmented Reality and Transmission through Virtual Space | | VR Therapy Design VR Simulation VR Model Embodiment of an abstract concept Visualization Experience Simulator | | | |
| | | Virtual Community Art | | Game Amusement | |
| Synthesized Reality | Reality Based Space | | | | |
| | Hyper Reality Space | | | | |

Fig. 1.4. VR as a human tool for the 3Cs and the 3Es.

1.4. Virtual Reality as a Human Tool for 3Cs and 3Es

Based on the perspectives mentioned above, virtual reality and/or telexistence provides humans with a tool for the 3Cs and the 3Es, as mentioned before. Figure 1.4 shows the roles of virtual reality as a tool and the characteristics of VR space in the form of a matrix. Typical usages are shown for each combination.

1.4.1. Control

In the field of remote manipulation of robots, teleoperation technology, which appeared following the development of nuclear power plants after World War II and the introduction of prostheses for the disabled, developed into supervisory control technology in the 70s. On the other hand, due to the advantages of direct operation, the development of exoskeleton human amplifiers, which cover the human body like armor and protect the body in dangerous environments while increasing the human power at the same time, was also studied in detail. Telexistence is the concept which

“aufheben”s the two technologies of supervisory control and exoskeleton human amplifiers, which developed rapidly after 1980.

1.4.2. Communication

It is predicted that networked reality can be used not only in offices and factories, but also at home, since the era of the information highway is just around the corner. Figure 1.5 shows an example of the usage of networked reality systems for communication, including the application to communications such as telemeetings, teletravel, teleshopping, and virtual community experiences with a sensation of presence.

This field is closely related to multi-media and Internet, which means that the provision of the network infrastructure is one of the pressing issues (DeFanti *et al.*, 2003). However, what we must keep in mind is that a mere quantitative improvement of the service is not at all sufficient for the dramatic changes in the field of conventional media. In order to make networked media a success, it is necessary to introduce changes in the quality and to introduce technology, which makes it possible to realize concepts such as virtual reality, which were previously considered

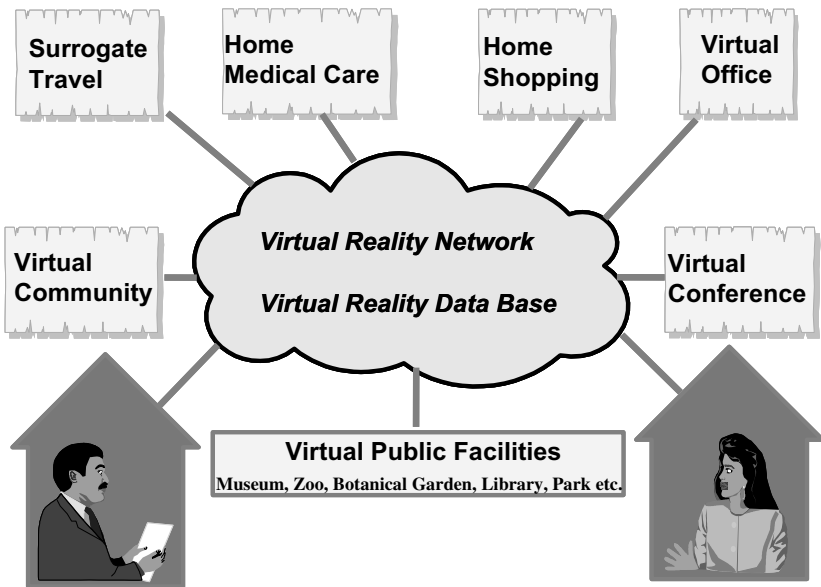


Fig. 1.5. Conceptual diagram of a networked reality system.

impossible. Thus, virtual reality is expected to be a great incentive to deliver high-speed and high-capacity fiber network access to each home.

1.4.3. *Creation*

Developments with respect to virtual reality can be seen in the fields of design and production. One of the important directions of development of future production systems is to manufacture products, which are adapted to the needs and the individuality of each user without losing exchangeability, expandability, or openness. However, it is not feasible to pursue products which are most appropriate to the needs of each person since the constant repetition of the design and production processes incurs high cost and wastes time, natural resources, and energy.

Virtual reality, which allows computers to be used in the fabrication of virtual products, which evoke the sensation of sight, hearing, and touch in the same way as real products, is expected to solve these problems. This technology also offers useful tools for the amplification of human creativity. We can embody very abstract ideas and concepts in our mind as concrete objects in virtual space and present these objects in a very concrete form to other persons by using virtual reality.

1.4.4. *Experience/Education*

Experience plays an important role in learning, training, and education. Application in education includes, for example, an ultimate simulation including an electronic experience simulator (van Dam *et al.*, 2003; Satava, 2005; Welch *et al.*, 2005).

1.4.5. *Elucidation*

Virtual reality provides rather useful and powerful tools for the elucidation of natural phenomena, for instance, scientific visualization as a tool for scientific-engineering research. Also, the use of VR as a tool for research of the functions of humans and other living creatures is promising.

1.4.6. *Entertainment*

It is not necessary to give a lengthy introduction to this usage since many relevant products are now available on the market. The only due addition is

that virtual reality provides a new medium, which embraces linguistic and pictorial means of expression and goes beyond them in expressing human ideas and concepts. Application of virtual reality as human communication media (Naemura, 2005) and artistic expression using virtual reality (Kuma, 2005) are typical examples of this new trend.

1.5. Virtual Reality Convergence

One of the reasons why virtual reality or telexistence attracts worldwide attention is that scientific fields, which have been regarded as belonging to completely different fields of research are likely to be united by the concept of virtual reality, as shown in Fig. 1.6. In the case of remotely controlled robots, the developments of nuclear technologies and orthotic techniques for manufacturing medical braces for handicapped people (such as artificial limbs) were combined after World War II to give rise to teleoperation technology.

In turn, this technology evolved into supervisory control in the 1970s, and, through the adoption of robotics, further developed into telerobotics in the 1980s. As a result, the idea of telexistence-based remote control,

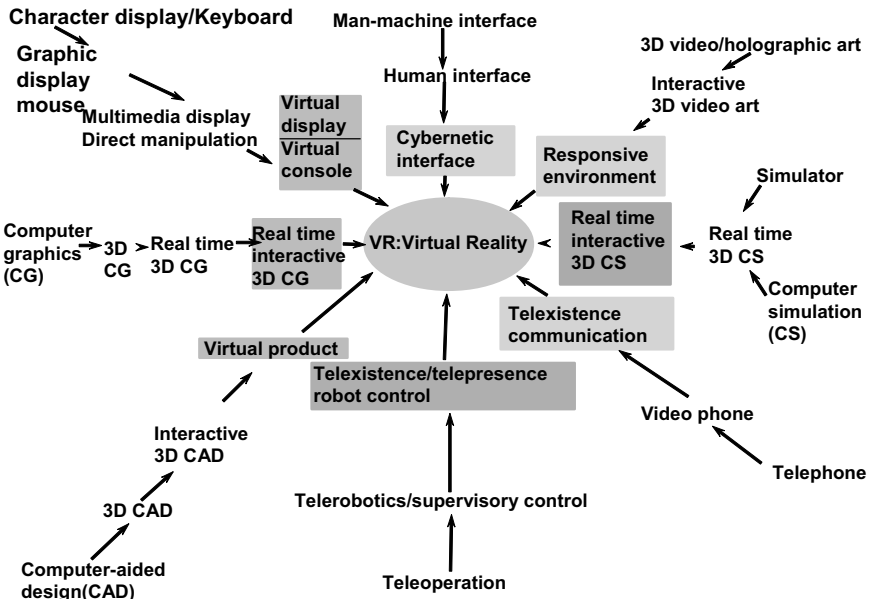


Fig. 1.6. Evolution and development of virtual reality.

which relies on telexistence 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 virtual reality.

In the field of CG, the conventional 2.5D display system, in which solid models are shaded and then displayed by using perspective transformation techniques, has advanced to 3D displays which provide the user with stereopsis (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 or her to look sideways or at a downward/upward angle at the image on the display screen as a virtual hologram. The interactive 3D CG techniques which are currently under development are at the shortest distance from the world of virtual 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 can allow designers to evaluate utilization prior to manufacturing and to implement design changes with ease if necessary. Design change data stored in the computer memory is readily available for producing "real" products if the memory is linked to a CIM (computer integrated manufacturing). The concept of virtual reality is of increasing importance to industrial production since it can aid the production of easy-to-use or much more advanced products, which are expected to be in great demand in the future and are more suited to individual user preferences. It also has the merit that it does not waste materials and energy in the production of intermediate products.

In the computer field, more user-friendly human-computer interfaces are desired. In addition to the currently prevalent character input by the use of keyboards, graphical displays, mouse input and object-oriented programming, there are many other possible interfaces, including multi-media displays, 3D mice, and direct input/output operations for communication with a more realistic sensation of presence.

Furthermore, the field of computer-generated simulations is experiencing a rapid development of real-time interactive 3D computerized simulation systems, which are intended for real-time operation on a near-real-experience basis. Simulators are also increasing their reality factor. Flight simulators and surgical simulators are typical examples of this development toward experience-type simulators with a sensation of presence.

The art and amusement industries are no exception. Artists and amusement designers are viewing virtual reality as a new art medium, which could surpass the existing ones with respect to the power and versatility of artistic expression.

In conventional human-machine interface design, humans need to adapt themselves to machines since humans are more flexible than machines. However, the creation of more human-friendly human-machine interfaces has been recently advocated. The next step is a cybernetic interface in which machines can come unilaterally closer to man's natural senses.

The above-mentioned developments will eventually result in the emergence of virtual reality. The rapid progresses in computer and sensor technologies and the increasing number of findings regarding human senses brought about by advances in human science have made virtual reality possible. Recently, many fields of scientific research which have advanced independently of each other have begun to focus on the concepts of virtual reality and telexistence and to view these concepts as key technologies of this 21st century. This encourages firms and organizations with enterprises in such fields to promote intensive research and development programs related to virtual reality and telexistence.

Furthermore, the concepts of virtual reality and telexistence are not simply common to the foregoing fields. The concepts themselves are based on common elemental technology, as will be described in Chap. 4. Therefore, a basic technology developed in one field can be readily applied in another field. This makes it more important to study all related fields as a single generic technology.