Robots for Telexistence and Telepresence: from Science Fiction to Reality

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Abstract

Telexistence, or telepresence, is the ability to be remotely present, i.e., exist and function at a remote location. For instance, a human operator can remotely manipulate objects with dexterity, while being provided with the feeling that he or she is physically present in the remote location. The telexistence and telepresence concepts will be used interchangeably in this paper. Although telexistence/telepresence as an engineering concept was proposed in late 1970s to early 1980s, a science fiction novel entitled ”Waldo” by Robert A. Heinlein described a primitive telexistence/telepresence master-slave manipulator system in 1942. Another novel, the “Brother Assassin” by Fred Saberhagen presented an almost complete concept of a telexistence/telepresence humanoid control system in 1969. A comic entitled “Jumborg A” produced by Tsuburaya Production illustrated another telexistence/telepresence system in 1970. It is interesting that some fictional robot control systems introduced in novels, comics, animations, and movies precede real telexistence/telepresence robotic systems. In this paper, the history of robots for telexistence/telepresence will be presented, from science fiction to real technologies.

Key words: Telexistence, Telepresence, Teleoperation, Remote robotics, Master-Slave System.

1. Introduction

Honda Corporation’s P-2, P-3, and Asimo humanoid robots and Sony Corporation’s AIBO have helped increase the popularity of robots in the world in general and Japan in particular. People are beginning to expect to see robots outside their traditional settings of factories. Although the physical and mechanical structures of today’s robots are very advanced, making these robots intelligent has remained a challenge. Recent popular robots have neither the ability to fully recognize their environments, nor the capability to efficiently plan their behavior. Therefore, in order to conduct useful tasks, which are not preprogrammed, the robots must be remotely controlled by human users. Currently, teleoperation of a robot is the most effective method for control of a robot. Telexistence is an advanced type of teleoperation that enables a human operator to perform remote dexterous manipulation tasks while being provided with the feeling that he or she is present in the remote environment [38][39]. This often involves the control of an anthropomorphic robot operating in a remote environment. Telexistence and the conditions for realizing telexistence was proposed by Tachi *et al.* in 1981 in Japan [38]. In the USA, the concept of telepresence, which is similar to telexistence, was proposed by Minsky in 1979 and 1980 [26][27].

Substantial effort has been made by various researchers to develop telexistence/telepresence through the feedback of rich sensory information which can be acquired by a remote robot to be provided to the operator in order to convey the real-time sensation of presence [11][12][13][37][34][40][2][32][6].

Although telexistence and telepresence were proposed as engineering concepts in late 1970s and early 1980s, a novel entitled “Waldo” by Robert A. Heinlein proposed a primitive telexistence/telepresence master-slave manipulator system in 1942. Another science fiction novel entitled “Brother Assassin” by Fred Saberhagen proposed an almost complete concept of telexistence/telepresence master-slave humanoid control

system in 1969. “Jumborg A”, a Japanese science fiction comic produced by Tsuburaya Production, proposed and illustrated a primitive telexistence/telepresence humanoid control system in 1970. This paper will present a number of actual telexistence/telepresence anthropomorphic robotic systems along with a number of fictitious systems presented mainly in Japan in novels, comics, animation, television programs, and movies. It is hoped that this paper will further popularize research on technical and scientific aspects of robots for telexistence/telepresence.

2. Telexistence/Telepresence Robotic Systems in Novels

This section describes a number of telexistence and telepresence systems which were described in science fiction novels.

Edward M. Forster proposed the ideas of primitive telexistence and computer networks in his “The Machine Stops” novel in 1909 [21]. Joseph Schlossel presented the ideas of remote robot operation and explorations on the moon by a remote robot in his novel entitled “To the Moon by Proxy”, which was published in Amazing Stories in October 1928. In Japan, Haruo Sato proposed the idea of an advanced communication system that could interactively send the sensory information including the virtual sense of touch in “Nonsharan Kiroku (Nonchalant Record)”, published by Kaizo in January 1929.

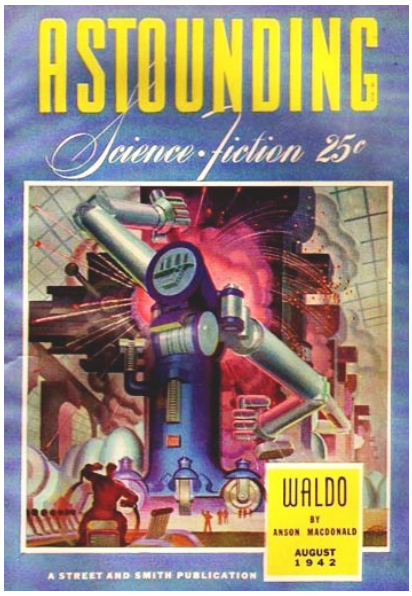


Fig. 1 Astounding, August 1942

R.A. Heinlein, using the pen name of Anson MacDonald, published a novel entitled “Waldo” in 1942. Fig. 1 illustrates the cover of Astounding Science Fiction in which “Waldo” appeared. Waldo, who is the hero of the novel, lives in an artificial satellite and he has developed various types of master-slave manipulators to work and to contact the people on Earth. These manipulators were called “Waldoes” by the people. Waldo would manipulate a number of Waldoes in front of a 4 by 5 feet three-dimensional color monitor in order to operate factories on Earth. The slave Waldo would move as the master Waldo moved, mimicking the movements. Waldo sometimes controlled a humanoid to meet people, however, the control method of the humanoid was not clearly described in the novel. Training the bilateral master-slave manipulators through the communication networks was also proposed in “Waldo.”

Heinlein can be credited for inventing the concept of telepresence, as M. Minsky has stated that he has been inspired by many concepts proposed by “Waldo” in his pioneering paper “Telepresence” [27]. Minsky wrote: “My first vision of a remote-controlled economy came from Robert A. Heinlein’s prophetic 1948 novel, Waldo.” It should be noted that the year of the publication of Waldo in Minsky’s comment in the paper is incorrect.

Heinlein continued his work on futuristic designs of telepresence by introducing the concept of a “Powered Suit” in his 1959 novel, “Starship Troopers.” The Powered Suit would be worn by a human operator and would directly utilize human muscle movements to control the powered movements of the suit. This concept has been the focus of a number of research efforts in the field of robotic human extenders.

The “Brother Assassin”, written by Fred Saberhagen in 1969, proposed a complete concept of telexistence/telepresence master-slave humanoid system. In the novel, the concept is described as follows:

“And a moment later it seemed to all his senses that he had been transported from the master down into the body of the slave-unit standing beneath it on the floor. As the control of its movements passed over to him, the slave started gradually to lean to one side, and he moved its foot to maintain balance as naturally as he moved his own. Tilting back his head, he could look up through the slave’s eyes to see the master-unit, with himself inside, maintaining the same attitude on its complex suspension.”

In order to use some functions of the master-slave system, e.g. a laser weapon, the operator pushes switches in his helmet by his jaw or his teeth. The switches seem not so convenient.

James Tiptree Jr. described a new telepresence technology, which connected one person’s brain to another person’s body through networks in the “The Girl Who Was Plugged In” novel, published in 1973.

3. Fictional Telexistence/Telepresence Robotic Systems in Comics, Animations and Movies

This section describes robots with telepresence and telexistence operations which have appeared in entertainment works in different media.

3.1 Jumborg A

The “Jumborg A” comic, produced by Tsuburaya Production and illustrated by Mamoru Uchiyama, was published in September 1970 issue of “Shogaku 2 nensei.” “Shogaku 2 nensei” is a magazine for second grade schoolchildren in Japan and “Shougakukan” is a Japanese publisher that published numerous books and

magazines for schoolchildren. Tsuburaya Production that was already known for its TV SFX program called "Ultraman" developed a new hero named "Jumborg A" for a new TV program before 1969. The term "Jumborg" was derived from the words "JUMBo" and "cybORG". The TV SFX program "Jumborg A" was broadcast in Japan in 1973.

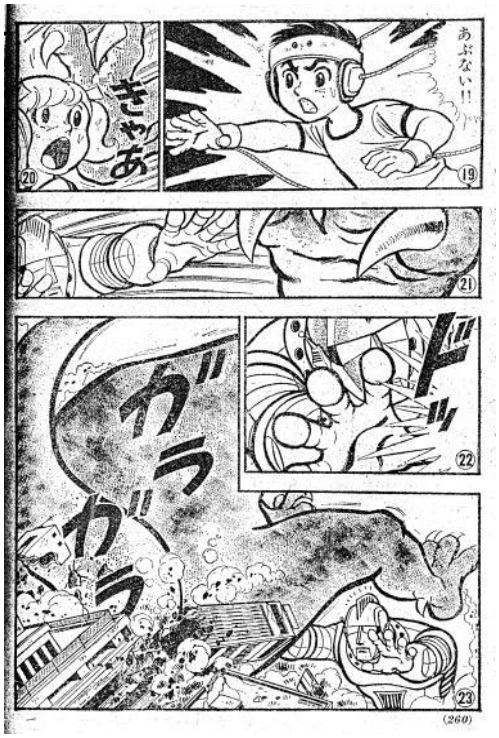


Fig. 2 Illustration of the robot control method from "Shogaku 2 nensei", September 1970, page 260 (The numbers correspond illustrations):

(19) The operator said, "(She is) in danger."
(20) The girl screamed.
(21) Jumborg A moved as the operator moved.
(22) Jumborg A pushed the monster.
(23) The monster was pushed away

The idea of the proposed control system is shown in the illustration of Fig. 2, where in order to save a little girl form being attacked by a monster, a hero named Shinichi moved as if he was pushing the monster. "Jumborg A", the slave robot, mimicked the movement and pushed the monster, tracing the movements of the hero. The display system for the operator is a large screen in front of him.

In order to make the comic and the TV program more attractive to children readers, the hero who controls the robot is an ordinary child who has never had any special training on using the robot. The underlying idea was that the telexistence and telepresence concept was designed is such a way that a child could control it. This is a very important consideration, as today's teleoperation systems require significant training, and the objective of most designers is to reduce the complexity in controlling such systems.

It can be inferred that the tactile or force feedback system is part of the control system. However, the actual method of the feedback system is not clear from the illustrations. A kind of feedback of a sense of pain is conducted by the control system. The operator feels a pain when the controlled robot is in bad condition. Such a system became popular in the telexistence robots appeared in entertainment works in Japan.

"Jumborg A" also used a voice control system for controlling the robot. In order to conduct tasks other than controlling the motion of the slave robot, the operator had to stop the telexistence control. The voice control system is an effective method to switch from the telexistence control to other control modes. For instance, when the operator lifted an object over his/her head through telexistence control, he/she could not scratch an itch, and voice commands were used to switch modes. The integration of voice control function in real telepresence control systems was done in early 1990s.

3.2 Yusha Raideen (Brave Raideen)

A television program, called "Yusha Raideen (Brave Raideen)," produced by Tohokushinsha Film Corporation was broadcast by Asahi TV Networks from 1975 to 1976. The upper half of the body of a robot named "Raideen" is controlled by telepresence. This program portrayed telepresence control using master manipulators with bilateral force feedback function.

3.3 Tosho Daimos (Fighting General/Captain Dymos)

The "Tosho Daimos (Fighting General/Captain Dymos)" television program was broadcast by Asahi TV Networks from 1978 until 1979. This TV program was produced by Asahi National Broadcasting Co., Ltd. and Toei Co., Ltd. A robot named "Daimos (Dymos)" was controlled by using the posture data from an operator's arms, combined with the Electromyogram (EMG) and the Electroencephalogram (EEG) signals from the operator. In this program, the concept of computer-aided control was presented where the control signal was calculated from the above data.

The artificial arm control using EMG signals has been investigated by a number of research efforts [5][23][9]. T utilization of EEG for control is more complicated than that of EMG, however, an EEG-based systems that can control a wheelchair and an EEG-based word processor are being designed and are currently under development [10][14][45][4]. The simple mechanical master manipulator with force sensors can measure the joint angles and the forces of the operator's arm. However, the contact tasks require the mechanical impedance of the operator's arm in addition to the joint angles and the force. It may be possible to calculate the mechanical impedance using EMG signals.

3.4 Mobile Suit Gundam

The learning-based computer-aided control was proposed in the television program "Mobile Suit Gundam." This show was directed by Yoshiyuki Tomino and produced by Nagoya TV, Sotsu Agency and Japan

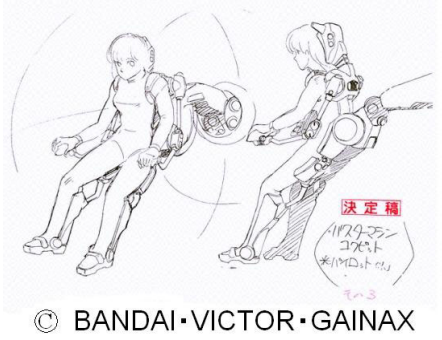
Sunrise. The program was presented by Nagoya TV network from 1979 to 1980. It should be noted that although Gundam was not manipulated by the telexistence method, the robot is included in this paper because of the fact that the learning cockpit could probably play an important role in robotics research.
Yuri Masami's comic, entitled "Mobile Police Patlabor," adopted the learning-based robot control system concept in 1989. In this work, the maximum performance of the robot can be achieved only after the operator teaches the robot numerous effective movement patterns over long periods of time. As of yet, a robot control systems that has a very effective learning capability has not been achieved. However, learning control is very popular in the control systems using EMG and EEG. It is believed that research on this type of learning cockpit system can become popular.
Furthermore, a novel display system that could superimpose two-dimensional computer generated images and text information over the camera image was described in "Mobile Suit Gundam." This approach has been utilized in some robotic research efforts.

3.5 Mobile Suit Z Gundam

The "Mobile Suit Z Gundam," program was directed by Yoshiyuki Tomino, produced by Nagoya TV, Sotsu Agency Co., Ltd., Japan, and Sunrise, was broadcast from 1985 until 1986. Although the control system of the robot was not a telexistence/telepresence control system, the surround-screen display was equipped with the cockpits of the robots. Research on the use of surround-screen display virtual reality systems became popular in 1990s [8][15].
An innovative display system that could superimpose three-dimensional computer-generated images over the camera images was described in a novel with the same title, written by Yoshiyuki Tomino in 1985. This approach is similar to a number of techniques used in the development of actual teleoperated systems. In order to overcome the time delay in teleoperation, Noyes and Sheridan proposed the predictive display [28] and used a hybrid display system that superimposed three-dimensional computer generated images over the real images captured by cameras. For robot operation, Matsui developed the Multi-Media Display system that could superimpose real-time 3-D computer generated images over the real image from cameras in 1980s [25].

3.6 Gunbuster (Aim for the top)

The "Gunbuster (Aim For The Top!)" program was produced by GAINAX *et al.*, and released in 1988. The control system of the slave robot named "Gunbuster" was similar in design to the ideal telexistence/telepresence control system which can be constructed using today's technology. The properties of the control system consisted of: (1) master manipulators for the entire body, (2) surround-screen display, and (3) cooperative control by an operator who controls the slave robot movements by telexistence/telepresence and another operator who controls the robot by using switches and other common human-machine interfaces. However, the displayed images were not three-dimensional. Fig. 3 shows the cockpit of Gunbuster.



(a) Master system of Gunbuster

(b) Display system and operator

Fig. 3 Gunbuster's cockpit from GAINAX

3.7 Other Fictional Systems

Another example of fictional robots for telexistence and telepresence appeared in the movie "Robot Jox" that was produced by Charles Band and Albert Band, and directed by Stuart Gordan in 1990. The operator generated walking motion commands for the legs of the slave robots by sliding feet on a plate.
The use force feedback by a device associated with the joystring or SPIDAR [19][33] was described in "Jushin Riger (Beast-God Riger/Bio Armour Riger)," a program produced by Sunrise and broadcast from 1989 to 1990. Joystring has been realized independently by Agronin [1] and Staudhamer in 1986 and further developed by Feldman.
The "Mobile Fighter G Gundam" program was produced by Nagoya TV and Sunrise and was presented by TV Asahi network from 1994 to 1995. The robots in the animation were controlled by an operator who wore a special flexible suit which measured the movement of the operator and conducted force feedback by the contraction of the material from which the suit was made.

4. Telepresence/Telexistence Robotic Systems: Science and Technology

Real humanoid (anthropomorphic) robotic systems operated by telexistence are presented in this section.

4.1 Mascot

In late 1950s, Mancini and Roncaglia developed a highly advanced robot system, named Mascot (Manipulatore Servo Controllato Transistorizzato) in Italy [24][3], as shown in Fig. 4. The slave robot had one stereo camera head, two slave manipulators, and a mobile base. The slave manipulator movements followed those of the master manipulator. However, the relationship of the head-mounted display (HMD) and the operator's hand were different from that of the camera and the slave robot hand. Due to the technical challenges which were unresolved at the time, the configuration of Mascot could not realize true telepresence/telexistence conditions, which are essential for the sensation of presence.

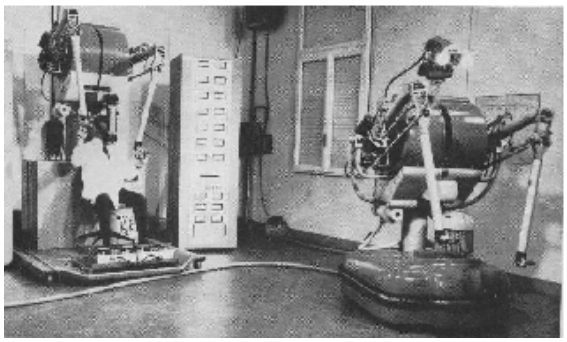


Fig. 4 Mascot

4.2 Greenman

Hightower *et al.* developed an anthropomorphic manipulator nicknamed "Greenman" at Space and Naval Warfare Systems Center (SSC), San Diego. This robot was built for remote presence demonstration from 1983 to 1988 [11][12][13]. Greenman as shown in Fig. 5 had an exoskeletal master controller with kinematics equivalency and spatial correspondence to the torso, arms, and head of the operator. Its vision system consisted of two 525-line video cameras, each with a 35degree field of view and an HMD.

SSC San Diego [35] described the main objective of Greenman as follows:

"Greenman provided SSC San Diego with valuable experience in teleoperation and telepresence issues and designs. Even with its simple claw hands and no force or tactile feedback, novice operators could readily perform manipulative tasks without training".

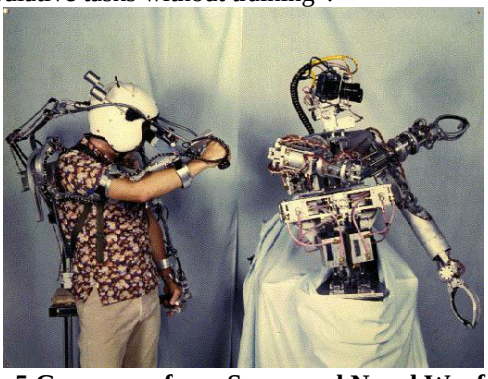


Fig. 5 Greenman from Space and Naval Warfare Systems Center, San Diego [35]

4.3 TOPS

The Teleoperator/Teleoresence System/Concept Verification Model (TOPS/CVM)[34], as shown in Fig. 6 was developed as the successor to the Greenman. The TOPS/CVM consisted of a 3-DOF (degrees-of-freedom) head, a 3-DOF torso and a dexterous, force-reflective 9-DOF hand coupled to a force-reflective 7-DOF arm.

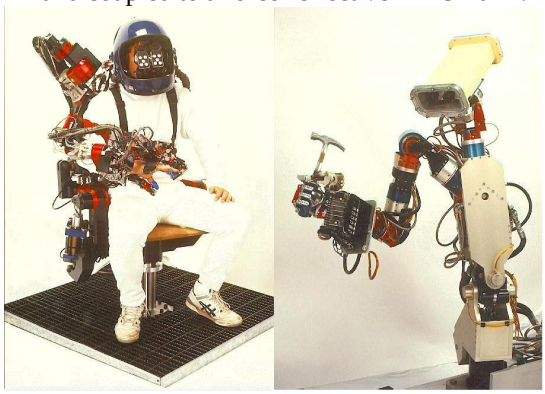


Fig. 6 TOPS from Space and Naval Warfare Systems Center, San Diego [36]

The operation of TOPS was described by SCC [36] as follows:

"... The operator controls the hand/arm combination through an exoskeletal controller, while the torso and head motions are controlled by the operator's torso and head motions. .... … The viewing system provides 1023-line monochrome video to the TOPS/CVM operator and has a 70-degree field of view with full stereo overlap. ... … The operator interface allows the TOPS/CVM operator to easily control all major TOPS/CVM functions and modes. This is done through the use of voice control and graphic overlay feedback. The second major interface, the supervisor interface, allows technical test personnel intimate access to all TOPS/CVM sensing and actuation systems."

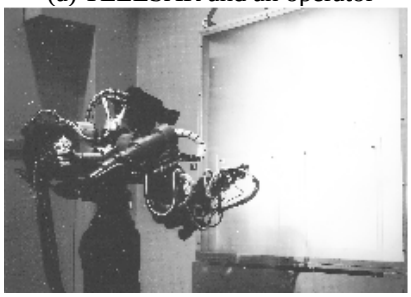
4.4 Telexistence Experimental System

Tachi, Arai, Maeda, Tsunemoto, Sakaki, Inoue, Oyama, Yanagida, and Yasuda have designed and constructed experimental telexistence system since 1988. The advantage of these system has been a concept called "Extended Telexistence," i.e., the use of a virtual reality (VR) environment between the master operator and the slave robot [40][41][42][32]. Fig. 7(a) shows the TELESAR (TELExistence Surrogate Anthropomorphic Robot) and the operator. In this system, the computer generates VR environments within which the operators can act freely.

The environment simulator for the VR system is used for the training of a task. This helps the operator with conducting the task in the real environment. If the VR environment is closely matched to the real environment, the operator working in the matched VR environment can control a slave robot operated in the real environment even when the visual conditions of the real environment are bad.

Since the master arm did not have force feedback capabilities, the slave arm was controlled by impedance control, as proposed by Hogan [16]. Small discrepancies between the real environment and the virtual environment were overcome by impedance control. The experimental system was used to successfully perform operations in an environment with extremely low visibility. Fig. 7(b) shows the operation of the system using the VR environment in a smoky environment.
A primitive Augmented/Mixed Reality component was integrated with the VR environment, where in the image generated by computer graphics, the extended telexistence system superimposes the VR image over the real image. The Augmented/Mixed Reality technology has been further developed and has been the basis for a number of research efforts.

(a) TELESAR and an operator



(b) Operation in smoky environment

Fig. 7 Telexistence Experimental System

4.5 The Cockpit for Advanced Robots

A Japanese national project from 1983 to 1990 , entitled **"**Advanced Robots Project,**"** has focused on the design and development of a telexistence/telepresence cockpit for a semi-humanoid robot with four legs which could operate in dangerous environment [29]. The anthropomorphic master arm's fingers were equipped with pressure generation devices. These devices consisted of air cylinders and were used to provide tactile information to the operator. The three-dimensional image was displayed on a screen placed in front of and in the upper direction from the operator. However, the presentation of the image was incomplete as the telexistence/telepresence system, since the operator could see in upper direction when the slave robot saw in lower direction while conducting tasks.

A number of typical manipulation tasks, such as handling a cocktail glass, rotating a steering wheel, handling a rope, and rotating a nut were successfully conducted.

4.6 tmsuk04

In 1999, tmsuk Co., Ltd. developed the humanoid type super-remote control robot, tmsuk04, which could be operated over a public mobile phone network with 64 kbps (kilo bits per second) data transmission speed such as the PHS network available in Japan. Fig. 8 shows tmsuk04 and its cockpit that can be easily carried to other locations.

Fig. 8 tmsuk04 from tmsuk Co., Ltd. [44]

4.7 HRP Super Cockpit

In 1998, the researchers of government offices, universities, and national research organizations in Japan began a national project, entitled, **"**HRP (Humanoid Robotics Project)" which aimed at the full utilization of a practical humanoid robot [18]. Fig. 9 shows the cockpit, which the University of Tokyo, Matsushita Electric Corp., and Kawasaki Heavy Industry have developed as part of this national project [43][17]. The general appearance of the cockpit resembles that of the cockpit proposed by the fictional Gunbuster program.
The main feature of this system include: (1) a surround-screen display, (2) master arms with force feedback, and (3) voice input system for motion control of the robot legs, as there are no master legs for controlling the leg movements of the robot.
One of the drawbacks of the surround-screen display is that some parts of display image are occluded by the master manipulator and the operator's own body [22]. This can complicate certain operations of the robot, especially contact tasks. The HRP super cockpit adopts a HMD for contact tasks. The HMD has a movable screen and can easily switch the head mounted camera image of the slave robot and the image of the surround-screen display.

Currently, the movement command generation for the robot legs by telexistence cockpit has a number of difficulties [20]. The HRP super cockpit does not have the telexistence type motor command generation function for the robot legs. The movement of the robot is directed by a joystick-type device (three-dimensional computer mouse). While conducting tasks, the slave robot keeps its balance without the need to consider the operator's status. The operator cannot control the motion of the legs of the slave robot. Therefore, the operator conducts operations as though he/she is riding a horse. In order to inform the operator of the status of the slave robot, the chair of the cockpit moves according to the posture of the slave robot.

A number of tasks such as picking a stuffed animal, picking a cup and passing it to a person, and operating a forklift, have been successfully conducted using the HRP system.

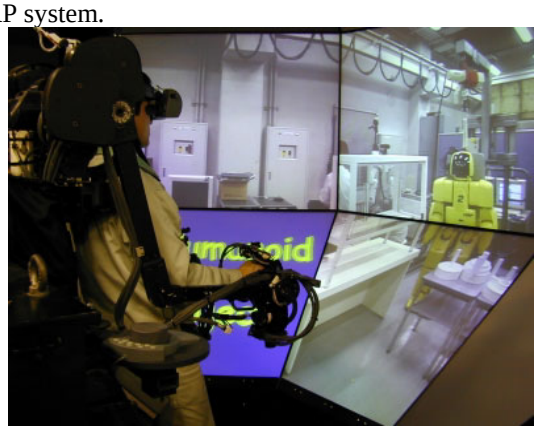


Fig. 9 HRP Super Cockpit

5. Conclusion

The art and the entertainment world have been and will continue to inspire scientific and technical advances in robotics. Although the artistic value of an art or entertainment work is not directly related to whether or not the technological predictions in the work have come true, the inspiration of a technology proposed in an artistic work can attract many people. Tremendous numbers of technological ideas have been first described in science fiction. It can be extremely valuable for researchers in robotics in general, and telepresence and telexistence in particular, to take advantage of potential technological forecasting offered by science fiction writers and producers. A proposed technical concept should be rigorously evaluated from the academic point of view even though the proposal could be generated by science fiction writers or artists. Obviously, the proposal is not enough, and the true realization of the concept using scientific and technical skills has to be done by researchers and engineers in the field.

In conclusion, it should be noted that this paper has focused on science fiction and other art and entertainment projects on telepresence and telexistence which has been produced mainly in Japan. Therefore, related work on arts and fiction could be missing from this paper. Any suggestions as to additional work (from science fiction to reality) which should be included in future revisions of this paper should be communicated to the corresponding author (first author) and it will be appreciated.

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