(3) Alter-Ego Interface Technology —Richer Communication through Robot Communication Terminals—

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A communication style in which robots serve as alter-egos to represent our own bodies in distant locations is being considered for future wireless network services. As a step in that direction, research is under way on telerobots that are operated via cell phones and humanoid robots that convey human gestures and body language according to signals from human bodies. Here we describe a human interface for these alter-ego robots and a new communication style that is made possible by such humanoid robot mediators.

1. Introduction

With the progress made in humanoid robot research in recent years, we can imagine a future in which humanoid robots reside in our homes and are a part of our daily lives [1]. In addition to robots controlled from remote locations by tele-existence technology and semi-autonomous robots controlled by instructions (supervisory control), we can imagine ubiquitous humanoid robots in the home, at the office, and in other places acting as communication tools like today's voice telephones and videophones, personal computers, and hand-held Personal Digital Assistants (PDAs).

Here, we propose interface technology for operating such robot-mediated communication and describe a new style of communication which that technology may engender.

2. The Alter-Ego Interface Concept

2.1 From Intellectual Communication to Bodily Communication

Communication by mail conveys with written characters may result in misinterpretations of the message and cause unintended disagreements that do not occur in verbal communication on the telephone, where a person's feelings can be expressed by tone of voice. Mental activity is based on intellect, emotion, and volition, so smooth communication between people cannot be achieved if emotion is not conveyed sufficiently. The images presented by videophones and the avatars of Virtual Reality (VR) systems convey the user's semblance and posture, so a sense of the user's virtual movement and feeling can be achieved in cyberspace. However, that still leaves something lacking in the conveyance of feeling in human communication. If, in addition to voice, video, and data, it were possible to remotely convey real bodily sensation to supplement the expression of emotions as well as the user's ambience and bodily movement by means of the actual body of a robot, then it might be possible to establish a bodily communication style that can bring emotions more into play.

Communication involves more than the simple transmission of information: a person's intentions and feelings are also conveyed when we communicate. We use the term alter-ego interface for this new style of robot-mediated communication that involves remote operation and conveyance of gestures by means of a robot avatar that has an actual body for conveying human bodily sensation and remote vision via a camera on the robot.

In future data communication, we believe there will be a need to shift toward communication in which there is more processing of body information in addition to intellectual recognition such as pattern recognition and understanding, which focus on data transmission.

2.2 The Real-Object Interface

In communication between remote locations, one can conceive of a humanoid robot that shares the location with the person you want to communicate with. You project yourself onto this robot and it acts as your alter-ego. The use of a humanoid robot as an intermediary for bodily sensation, the projection and input of feelings, and the presentation and sensing of data via the five senses, etc. can produce a kind of virtual teleportation. Tele-existence [2] and tele-operation [3] technology has been developed for remotely performing tasks and searching remote locations with remote-control robots. Tele-existence involves the remote operation of a humanoid robot via a network by operating an exoskeleton-like master arm from within a super-cockpit. Furthermore, conceptual research that can be applied to the implementation of an immersive, exoskeleton-like powered suit rather than remote operation tasks, has been done. One example is the PITMAN framework, in which operation control is based on the processing of brain excitation states obtained as electromagnetic signals from the brain, which could be called the ultimate human interface (**Figure 1 and 2**) [4], [5]. DoCoMo is pursuing research on alter-ego interface technology to eliminate the restrictiveness of the fully immersive supercockpit kind of human interface and achieve a tele-existence environment that is freely available at anytime, even in a mobile communication environment. Specifically, the measurement of high-density biological signals and measurements of the human body to determine the state of the operator are being investigated (**Figure 3**). The information about the body obtained by such measurements is transmitted to a humanoid robot that serves as an alter-ego for the operator—one that has size and weight—rather than to a virtual electronic avatar. Thus, the alter-ego interface can be called a real-object interface because it employs a humanoid robot that has an actual physical body. The significance of this approach is the sense of presence provided by the real physical body.

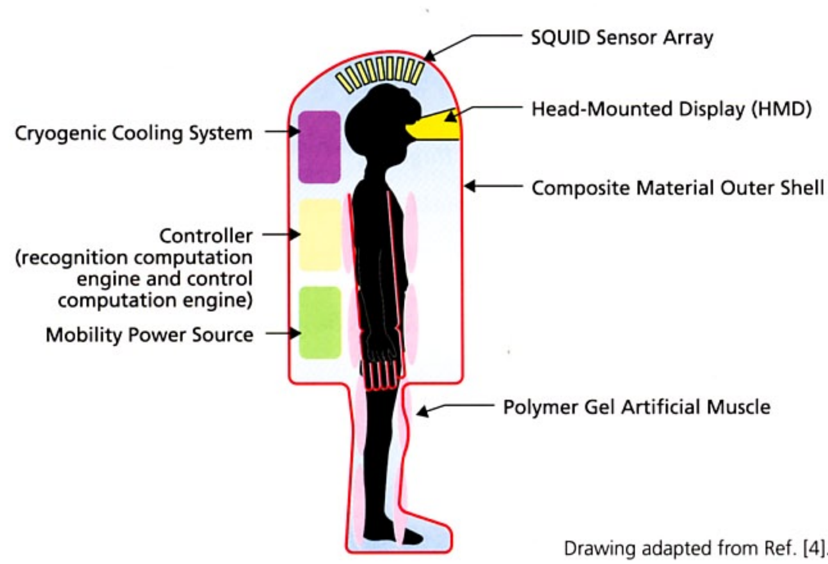


Figure 1 Conceptual Diagram of PITMAN (J. A. Moore et al., 1980s)

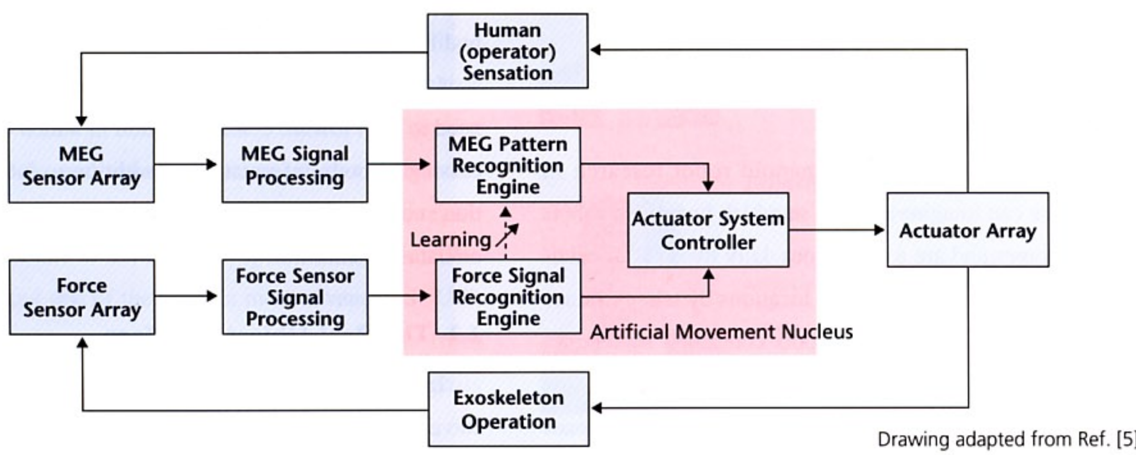


Figure 2 The PITMAN Signal Control System (from conceptual research by J. A. Moore et al.)

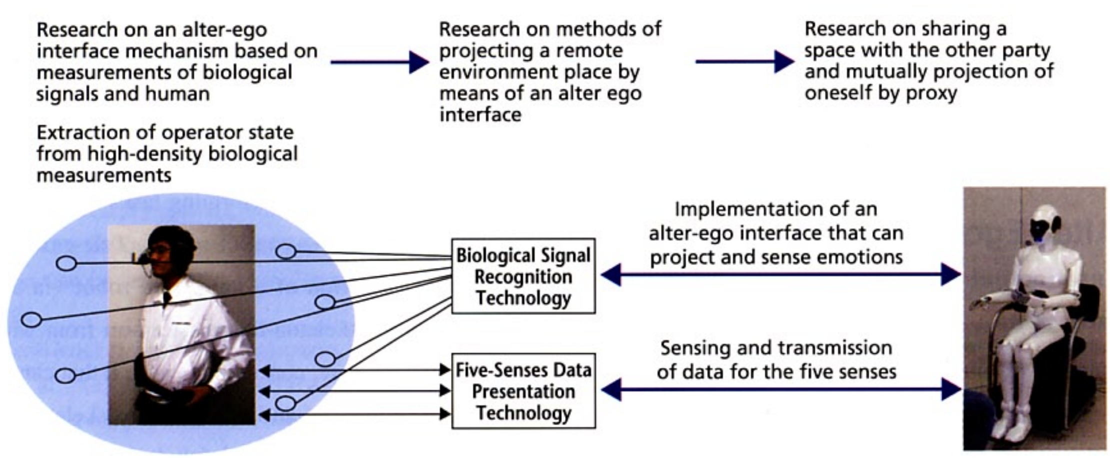


Figure 3 Virtual Teleportation by an Alter-Ego Robot

2.3 Non-Dissociative Communication

The basis of non-dissociative communication is "now and here," the sharing of a space and time.

Although the development of data communication technology in the 20th century has basically followed the Shannon-Weber model, that model originally dealt with information theory that concerned the transfer of information without any consideration of human beings. However, human communication involves an element that is inseparable and cannot be externalized, so such separation in the transfer of information is not possible in effective human communication. In a living society, communication is not done by means of information that is separated from the self: indeed, communication that does not separate self from others is normal, so media technology that takes considering body language that conveys subtle information is needed [6]. In communication between remote locations, it is generally difficult to create a shared space, so one is usually dissociated from the other party in the communication. If a communication system that supports the exchange of body movements (communicability) could be introduced, then non-dissociative, co-creative communication in which context is shared by the communicating parties could be achieved. For example, while context is easily shared in face-to-face communication, it is difficult to share context in non-face-to-face communication at a distance, because voice or written messages serve as the means of communication, as is illustrated in **Figure 4** [7]. For those reasons, we have investigated various methods that could lead to a new type of human interface that employs cell phones and a new type of gesture interface based on biological signals for application to a humanoid robot whose purpose is to mediate communication so as to accomplish the sharing of time and space that accompanies bodily coherence.

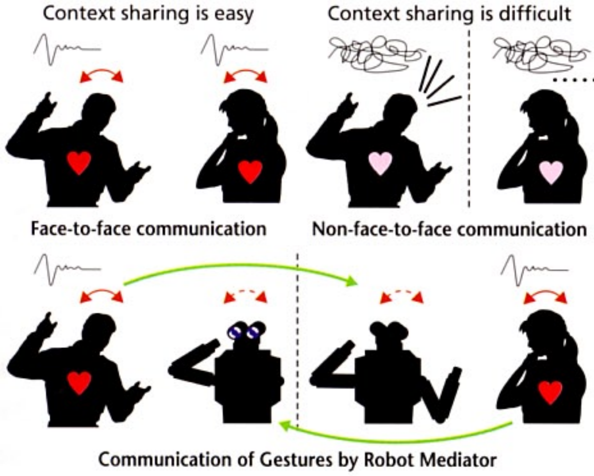


Figure 4 A Communication Concept

3. Remote Robot Operation of a Hand-Held Device

3.1 Hand-Held Human Interface

Considering various forms of remote operation of a robot by a cell phone from the viewpoint of controlling an alter-ego robot, an application for remotely operating a pet dog robot via a video-capable cell phone has already been developed. This implements remote robot operation by mobile sensing of the operator's state by means a wearable terminal or hand-held device wherever the person happens to be rather than by enclosing the operator in a supercockpit type of interface.

There have already been proposals for applications that perform extremely simple domestic assistance tasks by remote operation of a pet dog robot, dinosaur robot, etc. via a network. Such applications include monitoring the home while the resident is away or monitoring the residence of elderly persons who are living on their own using the robot's eyes or sensors, or caring for pets while their owner is away from home by remote operation of a mobile home robot that is equipped with arms. A business model has also been proposed in which robots that are connected to a network are rented and delivered to homes as needed. Considering disaster response systems, such as ones for remotely searching for victims in rubble by using a highly mobile wearable terminal and remotely controlled robot or monitoring the disaster area from above with a remotely controlled unmanned robot helicopter, technology from the disaster response robot competitions of recent years (e.g., RoboCupRescue) is also likely to be useful in the future.

3.2 Evolution Steps of the Alter-Ego Interface

The evolution steps of the alter-ego interface assumed when considering hand-held or wearable terminals for robot operation are shown in **Figure 5**. The first step is 'human remote operation' (tele-operation), in which instructions are given to a colleague at a remote location via a hand-held videophone. That will be followed by tele-operation of home appliances by cell phone and will evolve further to the implementation of robot tele-operation by a human operator. There will not only be the simple operation of armed and legged robots by means of master-slave arms, but also supervisory control, in which the robot receives instructions for performing tasks on the command level

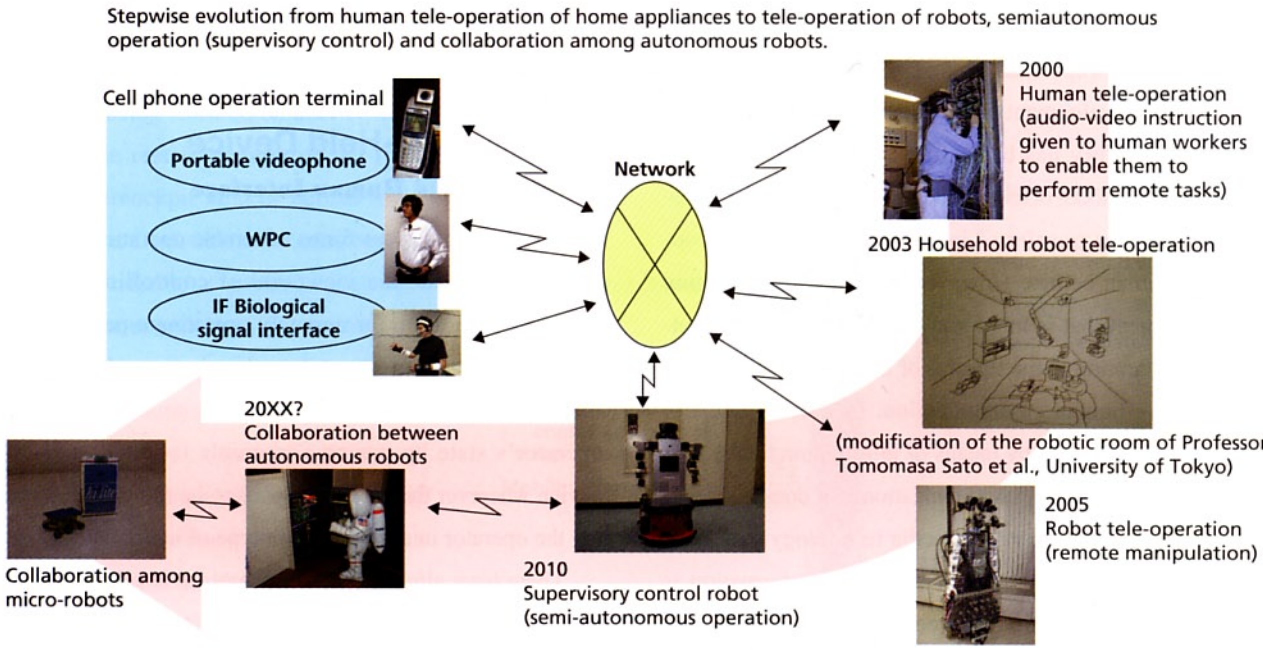


Figure 5 Evolution Steps of the Alter-Ego Interface

and then executes the tasks semi-autonomously. We expect that we will soon reach the stage where multiple intelligent robots that have a high degree of autonomy will engage in wireless communication to collaborate on tasks autonomously.

3.3 Videophone Alter-Ego Robot Operation Interface

An experimental system in which a mobile robot that can monitor a remote location while moving about under remote control by videophone is shown in **Figure 6**. The direction of robot movement is controlled from a remote location while the video image is monitored by videophone via the camera mounted on the robot [8]. Aside from the difficulty of operation caused by network and system delays, the narrow field of view of the robot's camera makes it difficult to grasp the situation at the remote location. Solving that problem has become a key issue for the human interface. As an attempt to solve this problem, multiple cameras (five in this case) were mounted in a circular arrangement on the head of the robot; the images from those cameras were displayed as a panorama on videophones similarly arranged in a circle. Even though there were seams between the screen images, the ability to understand the robot's position in the remote location was excellent because of the wide 180-degree field of view and the high resolution of the images obtained from the five independent cameras, even thought there was some lack of perspective fidelity in the horizontal direction [9].

Figure 6 Experimental Mobile Robot for Remote Monitoring via Videophone

3.4 Supervisory Control of an Alter-Ego Robot by Cell Phone

An experimental system for command operation of an alter-ego robot using a virtual cell phone is shown in **Figure 7 and 8**. The video image from the head of a remotely located robot is displayed on the screen of the virtual videophone, and the operator selects from among command buttons and instruct the alter-ego robot to produce pre-registered gestures. The live image of the operator's face is captured by the camera of the cell phone and displayed on the screen that is mounted on the chest of the alter-ego robot. This aims to reduce the anonymity of the remote robot and let people near it know who and from where it is operated [10]. This system is on display in the visitor exhibition hall at the DoCoMo Yokosuka R&D Center.

Figure 7 Virtual Terminal for Alter-Ego Robot Operation

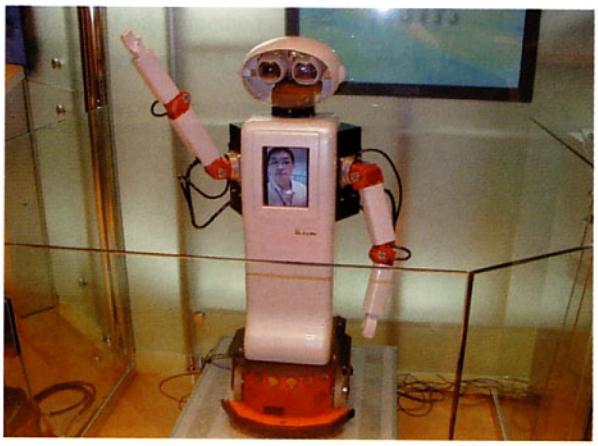


Figure 8 Alter-Ego Robot (display for visitors at the DoCoMo Research Laboratory Exhibition Hall)

4. A Communication Style Involving Humanoid Robot

4.1 Communicaion by a Robot with Emotions

Remote operation by cell phone is simple and useful from the viewpoint of operation, but as a communication system it suffers from the dissociation problem, so it is inadequate as a non-dissociative, co-creative communication system. There is a proposal currently for an interaction environment that supports smooth dialog in communication with someone at a remote location by using a robot that can process an utterance as a time series audio signal and can nod and gesture to mediate in the communication [11]. DoCoMo has also tried virtual experiments for conducting dialog via a network in which robot terminals are placed at the two locations [10]. The robot shown in **Figure 9** presents the face of the other party on the display screen on its head and presents an image of his or her surroundings captured by a wide-angle camera on the display screen on its chest. Knowing the surroundings of the other person from the video image rather than receiving a simple dialog alone helps one grasp the other person's situation, whether he or she is presently in calm surroundings or in the midst of a busy, noisy situation, so it aids in the sharing of place. However, although the robot itself is mobile, it is not capable of reproducing gestures with the upper half of its body, so it is not adequate for introducing emotion to aid in smooth communication.

4.2 Merits of the Humanoid Robot Communication Terminal

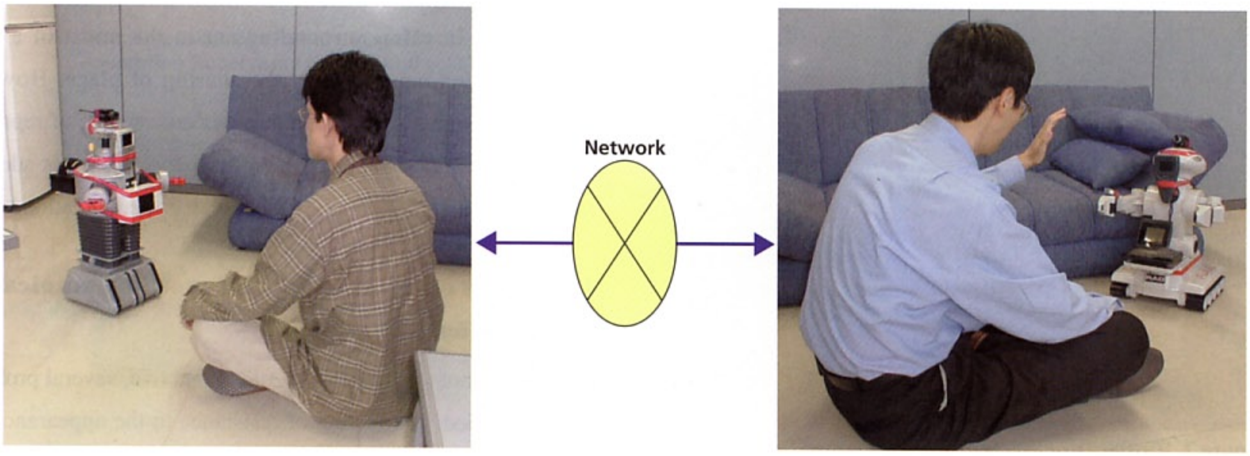
In the robot experiments mentioned above, several problems were identified: i) a feeling of resistance to the appearance of a living face on a robot, ii) the sense of incongruity arising from the fact that the robots were not life-sized, iii) a lack of feeling of substance, iv) insufficient bodily sensation due to the robot's lack of emotion and gesture movements, and v) a lack of inertia. One merit, on the other hand, was the enjoyment of two-way, real-time robot-mediated communication. To solve the problems identified in those experiments, we constructed an experimental platform for full-size humanoid robots for use in mediating communication [12]. The external appearance and specifications of the robots are presented in **Figure 10**.

Humanoid robots that walk on two legs have already been developed, but focusing on the conveyance of human gestures, we placed importance on the reproduction of upper body gestures and expressions made with the hands and fingers. To reduce the psychological uneasiness that may arise when people communicate via a robot intermediary, we gave the robot two legs, even though they are not functional. Mobility for the humanoid robot is accomplished by wheels on the chair that supports the robot, considering the current limitations and reliability of bipedal ambulation. This approach allows the upper body of the robot to move without restriction, enabling free movement in a barrier-free space.

The robot face is a translucent visor behind which are light emitting diodes (LEDs) of various colors. The intensity of the light produced by the LEDs in the mouth area is controlled by the loudness of the operator's speech, and emotion can be expressed by changing the color of the light according to the content of the speech (**Figure 11**).

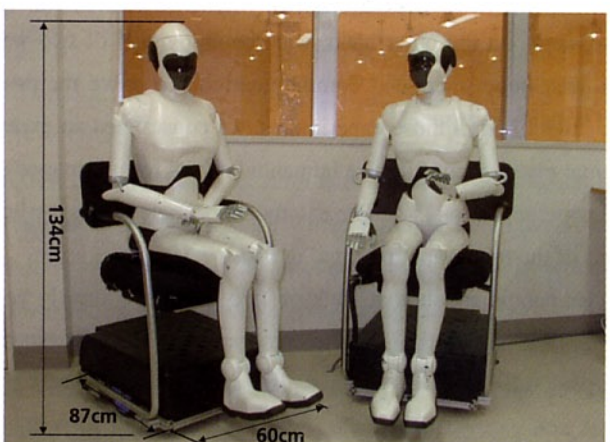
4.3 Gesture Information Transmission by the Full-size Humanoid Robot with Electrical Signals from Muscles

For the purpose of conveying the operator's own gestures to



Two-way communication via a mobile alter-ego interface

Figure 9 Experiments on Communication with an Alter-Ego Interface with Emotions Serves as an Intermediary

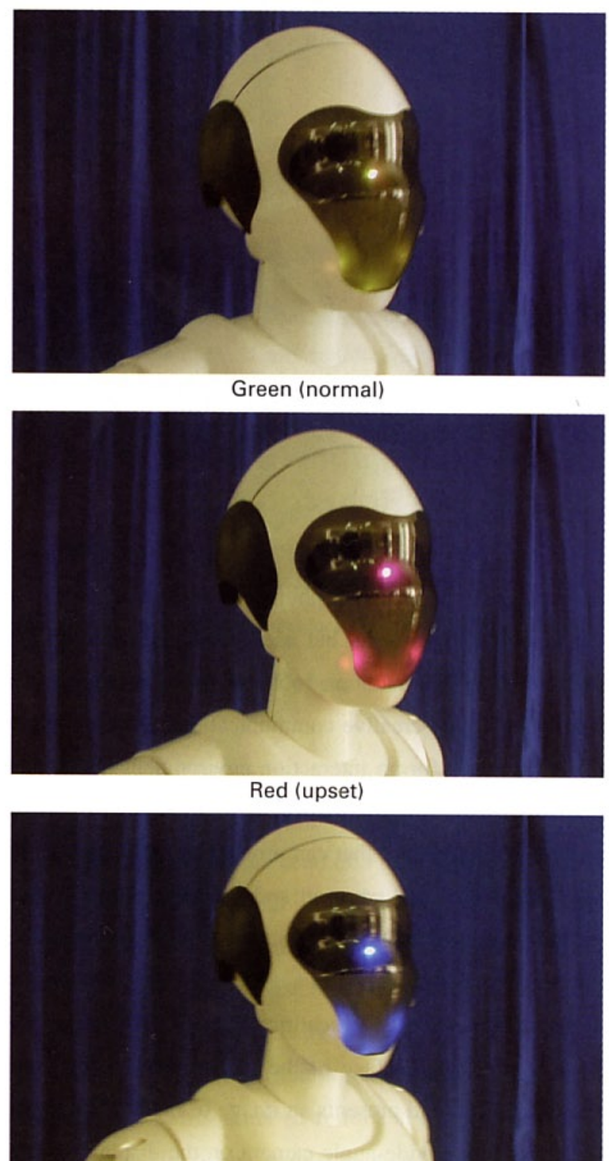


Entire body	31 DOF	Head	3 DOF
Fingers of one hand	6 DOF × 2	One eye	2 DOF × 2
One arm	6 DOF × 2		

Mounted on a mobile platform equipped with infrared sensors
Multiple multi-colored LEDs on face
Exterior is 3D optically cured plastic with some aluminum parts

Figure 10 Constructed Full-Size Humanoid Robot

the humanoid robot in front of him, which serves as a human interface for relaying the information via a network to the remote humanoid robot, we are contriving a method in which myoelectric signals are detected on the skin of the operator and processed for pattern recognition. We have already achieved control of five fingers and ten joints of a robot hand by detecting the electrical signals from muscles on the skin surface at the place where a person wears a wristwatch and performing pattern recognition on the signal data with an artificial neural network [13]. That system also employs the method described in section 4.2 (**Figure 12**). Furthermore, in the recognition of arm and shoulder movements, we achieved recognition of three of the six Degrees Of Freedom (DOF), the number of axes of rotation



Green (normal)

Red (upset)

Blue (calm)

Figure 11 Facial Expression Representation by Multi-colored LEDs

of the robot joints, from myoelectric signals detected by skin surface electrodes placed on the upper arm (2) and shoulder (3) on both sides of the body (**Figure 13**). The recognition is being extended to six DOF by employing a new method of signal processing.

A wearable data collection system in which sensors are mounted on clothing, such as a data suit, can be considered for detecting human movements in a mobile environment. To detect myoelectric signals, however, it is effective to attach electrodes at just some of the points on multiple muscles, so it is possible to embed skin electrodes in worn items such as bracelets or supporters. Furthermore, this approach is not affected by the restrictions of other methods, such as motion capture by a camera that is offset from the person. In recent years, active electrodes that incorporate preamplifiers have enabled stable, low-noise detection of myoelectric signals at the skin surface in ordinary indoor and outdoor environments or in vehicles. The low cost of sensors and amplifiers, the simplicity and convenience of sensing, and the high processing speed of personal computers have made possible the real-time processing of multiple channels of muscle signals. Given an application program with sufficient accuracy and reliability of finger gesture detection, a fully practical accuracy is achieved (the root mean square error is about 20 degrees). We believe that even higher accuracy in recognizing joint angles can be achieved in the future by sensing with, for example, about ten electrodes arranged in a circle in a bracelet-type sensing device. Experiments on such a device are currently in progress.

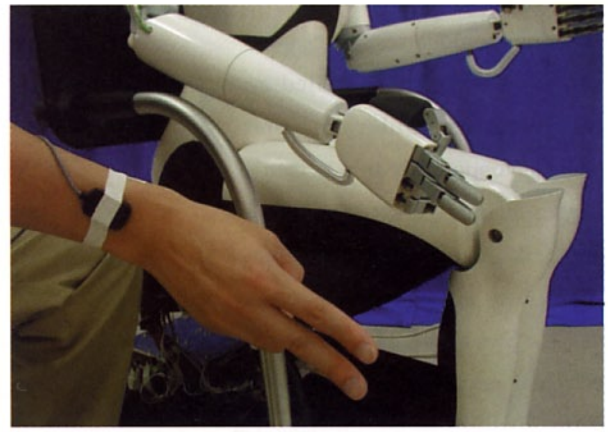


Figure 12 Operator's Finger Movement Sensing Electrodes and Humanoid Robot Fingers

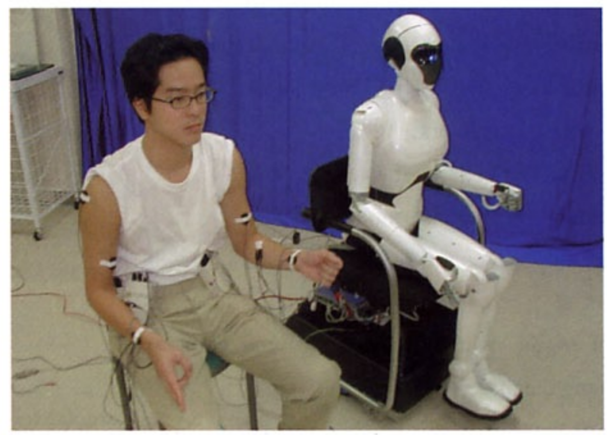


Figure 13 Operator and Humanoid Robot

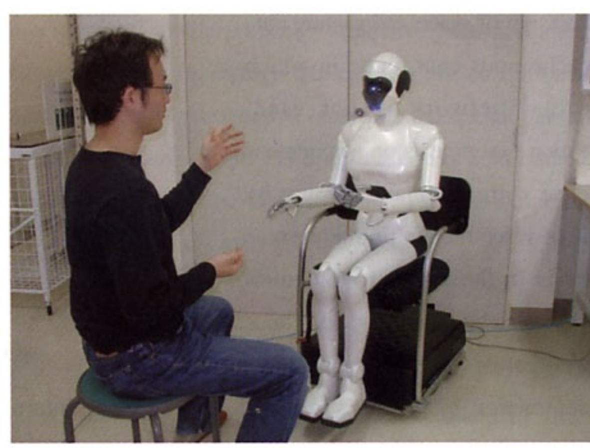


Figure 14 Communication Mediated by a Humanoid Robot

4.4 Three Communication Modes for the Humanoid Robot

We propose three modes for communication mediated by a humanoid robot (**Figure 14**).

(1) Synchronous Chat Mode

In this mode, two persons at remote locations chat in real time via a network, and gestures are sent via the network to each person's alter-ego humanoid robot, which is located near the other person. This is the same form of communication as chatting on a personal computer. In this mode, the movements of the master are transferred to a humanoid robot that operates in slave mode. This form of two-way communication using two tele-existence robots is called the synchronous chat mode (**Figure 15**).

(2) Asynchronous Mail Mode

This mode is similar to e-mail exchanged on computers and is thus called the asynchronous mail mode. A person's voice and gestures are conveyed to the humanoid robot at that person's location and transferred via a network to a remotely located humanoid robot, which reproduces the voice and gestures. However, the information transfer is not done in real time; rather, the receiving party plays back the transmission at a time of his own convenience (**Figure 16**).

(3) Autonomous Response Mode

The autonomous response mode employs what might be called an intelligent humanoid robot that responds autonomously to a person's inquiry or utterance (**Figure 17**). For example, the humanoid robot might autonomously interpret the message "Tell Mr. 'So-and-so' 'something-or-other'." and autonomously convey the gestures involved in the message via the network to the humanoid robot at the recipient's location according to the content of the message. This mode could conceivably also be used locally, without a network.

Another form in which the autonomous response mode could be used involves connection via the network to a remote large-scale intelligent engine or natural language processing database.

At the time of this writing, experiments are being conducted on the transmission of voice and gesture data in synchronous chat mode in which an actual network is not used. Simulation experiments on autonomous response with a humanoid robot by means of voice recognition and voice synthesis in the asynchronous mail mode are also being conducted. Those experiments are creating the feeling that interaction by gestures in addition to voice maintains a freshness and sense of presence that is absent with the video and audio of conventional videophones, so even if the live face of the other party is not seen, the mutually enhancing effect of voice and gestures made by the actual body of the life-size humanoid robot creates an impact, a sense of presence, and a sense of substance that are not produced by an avatar generated by computer graphics. The results of these experiments are making it difficult for anyone to deny that the movement of a substantial, full-size humanoid right before one's eyes is appealing to people.

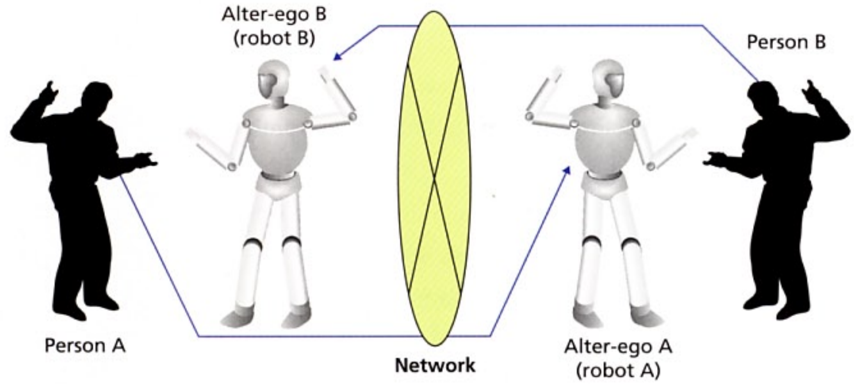


Figure 15 Synchronous Chat Mode

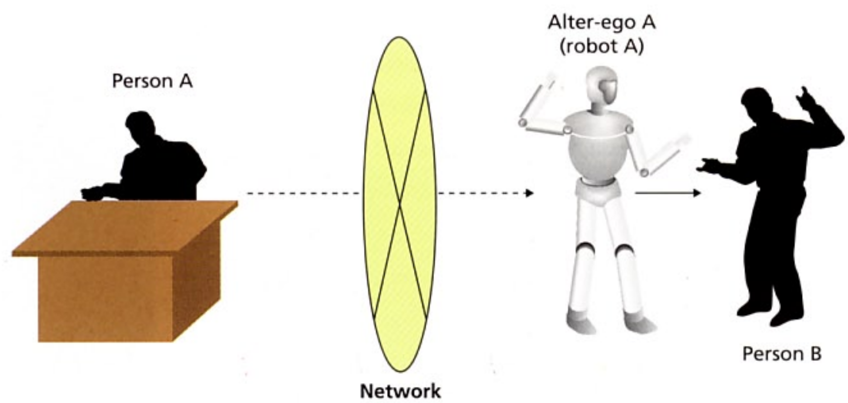


Figure 16 Asynchronous Mail Mode

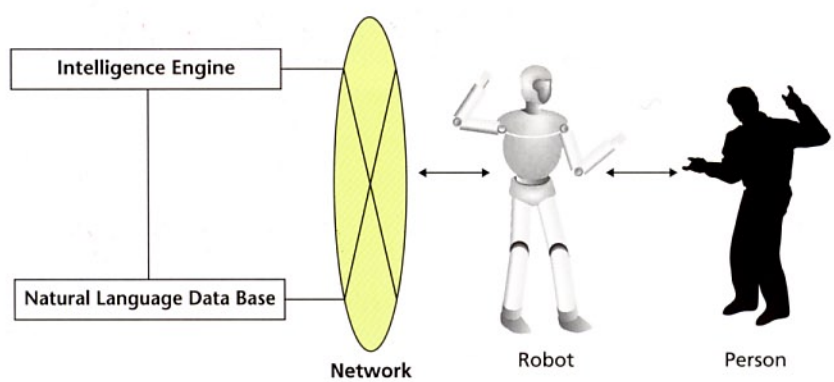


Figure 17 Autonomous Response Mode

4.5 Remote Control of an Alter-Ego Robot by Measuring Brain Waves and Brain Magnetic Fields

The ultimate human interface for transferring our own intentions to an alter-ego robot is thought transfer, in which we simply think of an action and it is transferred to the robot [14]. A human intention to perform a movement involves the generation of a series of voluntary movement operations by the supplementaly moter area and presupplementaly moter area of the brain, etc., a process that requires a complex time structure. That process produces signals that can be detected on the scalp in the form of minute variations in electric and magnetic fields mixed

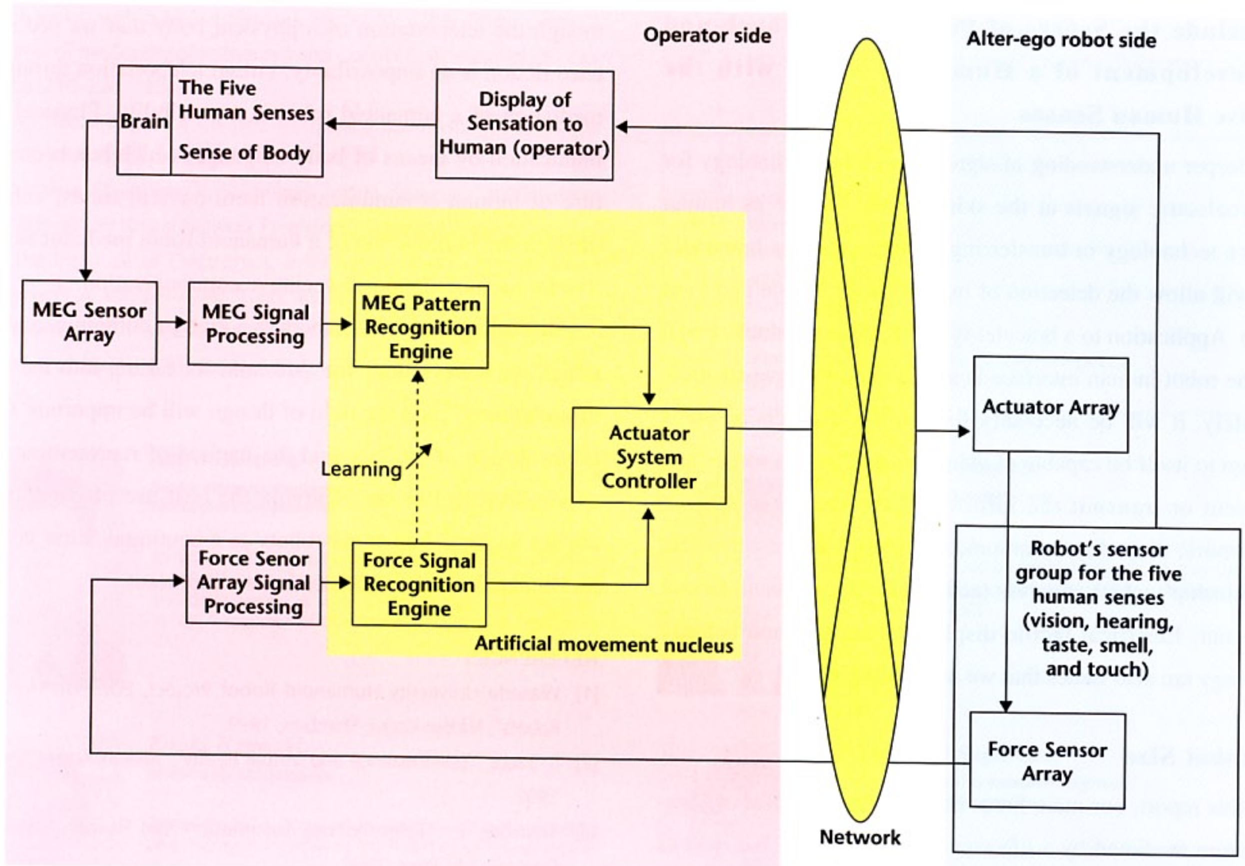


Figure 18 Example of MEG-Based Remote Control for Alter-Ego

with the background brain wave patterns which called Readiness Potential (RP) and Readiness Field (RF) [15]. However, it is technically difficult currently to perform pattern recognition on those signals in real time. In the 1980s, the PITMAN framework was conceived with the objective of controlling an exoskeleton-type powered suit by means of a brain magnetic field interface. However, research and development on that concept was abandoned because of the limits on the sensitivity of the superconducting quantum interference device (SQUID) magnetic flux meter, the electromagnetic shielding technology, and the poor performance of computers at that time. Now, however, magnetic shielding technology that employs the Meissner effect, today's high-temperature superconducting materials, expected improvements in future sensors, and advances in computer performance and miniaturization are opening up the possibility of realizing such human interface technology based on the MagnEtoencephaloGram (MEG). Even controlling a remote alter-ego robot by means of an MEG human interface via a network and receiving sensory feedback by various methods (for example, electrical stimulation of the median nerve or the inner ear or magnetic stimulation of the brain) is not a futuristic dream. A conceptual example of MEG interface control of the proposed remotely controlled alter-ego robot is illustrated in **Figure 18**. Studies are currently under way on methods for recognizing temporal and spatial patterns of electrical excitation within the brain based on MEG and EEG data and on pattern recognition for multi-channel temporal and spatial MEG and EEG data.

5. Future Issues

5.1 Establishment of an Entrainment Evaluation Method

The experiments on communication mediated by full-size humanoid robots aimed at non-dissociative communication have demonstrated the appeal of communication in which gestures are exchanged via robots that provide a physical body presence, but they have not provided adequate quantitative evaluation. When smooth communication is taking place between people who are together at the same place, unconscious mutual synchronization of body movements (entrainment) occurs, and it has been reported that phase synchronization even affects breathing and heartbeats [16]. In future work, we will use such phenomena in quantitative evaluation of the communication system.

5.2 Extension of Human Interface Technology to include the Senses of Pressure and Touch and Development of a Humanoid Robot with the Five Human Senses

A deeper understanding of signal processing technology for the myoelectric signals at the skin surface for use as human interface technology in transferring gesture data to a humanoid robot will allow the detection of human finger torque and joint tension. Application to a bracelet-type wearable terminal as well as to the robot-human interface is also a topic for investigation. Ultimately, it will be necessary for a robot that acts as one's alter-ego to itself be capable of using the five human senses and to present or transmit the information to the other person. Furthermore, in bodily communication, not only gestures, but also 'skinship', which involves tactile data (active touch) cannot be left out. Electrical tactile display technology and sensing technology are also issues that we are dealing with.

5.3 Robot Size

In this report, our main focus has been the proposal of communication mediated by a life-size humanoid robot, but, just as scale-models can have various sizes, the question of what sizes are acceptable for a humanoid robot mediator is also an issue.

5.4 Artificial Intelligence

Robot technology and artificial intelligence research are, ultimately, two sides of the same coin. Artificial intelligence based on signal processing is seen as having reached a temporary impasse, but the ultimate problem that cannot be avoided in the future is the artificial construction of intelligence, knowledge, and consciousness in a robot that has an actual body and is equipped with sensors and actuators [17], [18].

6. Conclusion

The communication style that we propose, which employs a full-sized humanoid robot mediator, holds great promise for future communication, in which humanoid robots act as communication terminals. We believe that the good relationship between wireless communication networks and humanoid robots will become increasingly clear. Even if the humanoid robot is not made intelligent, it can be operated on a master-slave basis, which will still enable telecommunication that involves embodiment in an actual physical body, which has not been possible with previous types of communication terminals. We believe that this is a very significant development. Even though the teleportation of a physical body that we see in science fiction is an impossibility, virtual teleportation through the mediation of a humanoid robot is a possibility. Physical communication by means of body language, which has been a feature of human communication from ancient times, achieved through the introduction of a humanoid robot mediator is effective for promoting non-dissociative communication.

Regarding humanoid robots as a kind of communication terminal, we believe that "the threshold for falling into the valley of uneasiness"* and the field of design will be important for the future design of the face and the method of representing facial expressions and so on. Studying the best use of collaboration among multiple humanoid robots as a communication interface and human interface schemes is also important.

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* A robot engineering term proposed by Professor Emeritus Masahiro Mori of the Tokyo Institute of Technology that points to the ill feeling produced when the outward appearance of a robot halfway resembles a human or animal

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GLOSSARY

CPU: Central Processing Unit
D.O.F: Degree Of Freedom
LED: Light Emitting Diode
MEG: MagnEtoencephaloGram
PDA: Personal Digital Assistant
RMS: Root Mean Square
SQUID: Superconducting QUantum Interference Device
VR: Virtual Reality