# 2 Toward the Realization of Situation-Sharing Communications Technology

## 2-1 Research on Communication Mechanism of Embodied Interaction

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We launch an investigation of communication mechanism of embodied interaction in Kehannna Human Info-Communications Research Center. We conduct our investigation in the following three fields, physiology, cognition, and behavior. In the physiological field, we extract the motion of each finger, extension and flexion, from electromyogram data by independent component analysis. We apply separation of fingers' motion to computer interface. In the cognitive field, we investigate the cognitive mechanism of the preverbal communication. We focus on both the development of childhood communication and its implementation on the humanoid robot. In the behavioral field, we study nonverbal information in human interaction. We measure the activity of communication and a degree of mutual understanding of intention using the motion of our face and head. We pursue our research so that the communication system becomes the social being and the quality of life.

***Keywords***
Embodiment, Electromyogram, Preverbal communication, Joint attention, Nonverbal Information

### 1 Introduction

We studied cognitive mechanisms of communication for an interactive system at the Kansai Advanced Research Center. We then constructed a dialogue system that allows interaction through a computer display using text and voice. Consulting systems for e-mail users[1] and Webdialeague system[2] are such dialogue systems that are accessed through a computer display. The analysis of dialogues conducted during cooperative work[3], a measurement of the meanings of words and contexts of text[4], analysis of the stability of the semantics of a language[5], and even comprehension of dialogues based on the Theory of Mind[6] were studies of communication extensively using speech literature.

In this study, although we developed a dialogue system on a computer, we never felt like we were talking to a human being when communicating with the system. As Dennett explained, we took design stance[7] on the system. This was reasonable to expect because the computer could only respond in the form of pre-programmed expressions in certain question-and-answer dialogues. Another probable reason for not achieving natural communication is that a computer does not have a mind. We finally found support for the contention that the above dialogue system suffered from an “absence of embodiment” in the experimental work of Kozima. Kozima created an infant robot “Infanoid3[8],” which is able to gaze into interlocutor's eyes, and another "Infanoid4[9][10]," who is an upper torso humanoid and creates joint attention with people.

Based on these results, we concluded that to achieve truly "human-like" communication, a dialogue system should have embodiment. Communication between humans always involve some physical movement as a means of conveying additional information. Even during non-visual forms of interaction, such as a telephone conversations and on-line chats, the participants sometimes attempt to imagine the actions of the interlocutor. We replaced such nonverbal gestures of the interlocutors with simulated actions to enhance supplementary comprehension of the interlocutor's feelings and intentions. Thus, by adding embodiments to a communication system, it may be possible to enhance the depth of interaction[11], as stated by Okada.

At the Keihanna Human Info-Communications Research Center (Keihanna Center), we conducted research on the following subjects:

- Recognition and application of finger motions using surface electromyograms
- Cognitive mechanism in preverbal communication
- Nonverbal information in interaction

This paper describes a study on the recognition and application of finger motions using surface electromyograms in chapter 2. In this study, we identified and estimated finger motions using surface electromyograms of the forearm. We then applied the results to a computer interface. Particularly, when the results were applied to an amputee, she indicated that the new interface allowed her to communicate as if she still had her fingers.

Chapter 3 describes the cognitive mechanism in preverbal communication. In this study, we focused on the development of communications during the preverbal period of an infant. Simultaneous activities are being closely coordinated: one is to construct cognitive models for joint attention, indirect experience and imitation; and the other is to employ this model as a cognitive module for a robot Infanoid. At the Keihanna Center, we intended to reproduce human-like interaction by combining developmental psychology and robotics.

Chapter 4 describes the use of nonverbal information in interaction. In this study, we measured dialogue voices and movements above the neck in face-to-face communications to quantify the activity during conversation and the degree of mutual understanding. When recording face-to-face communication between remote locations, we used a system that enables transmission of high modality information by using a two-way mirror to ensure that the speakers can make eye contact. This study may be applied to improve representation of emotional states in embodied systems like robots.

The above studies relate to embodied communication based on physiology, cognition, and behavior. These studies will help us construct an embodied communication system that can eventually communicate as effectively as human beings.

## 2 Recognition and application of finger motions using surface electromyograms[12]

When we flex and extend our fingers and arms, electric pulses are conducted through motor nerve fibers to control the contraction of muscle fibers (constituting a motor unit) in our arms. Our first action was to examine whether measured electromyogram (EMG) signals can be applied to various interfaces when a system can recognize the patterns of finger motions in the EMG signals. Such signals may be within a range of intended finger motions for physically handicapped persons and finger motions for non-handicapped persons.

For this purpose, interfaces using electromyogram signals have the following features:

- Electromyogram signals indicate the force of the fingers while a data glove measures their positions.

- Electric pulses in muscle fibers give fairly high sensitivity to actions.
- Electromyogram patterns corresponding to the finger motions may be obtained from the muscle fibers in amputees who retained their forearms.
- By using multi-channels EMG, electric pulses and information of phases may be analyzed and such information may be applicable to the noninvasive estimation of a motor unit.

These features indicate that electromyogram signals may allow amputees and handicapped persons to control artificial hands, operate equipment, and use various kinds of computer interfaces[13]~[17]. These signals may also be applied to interfaces and manipulation devices that use biological signals from non-handicapped persons as well.

We conducted noninvasive 16-channel measurements of electromyogram signals on the skin surface (surface EMG) of the forearm to identify and determine finger and wrist motions. The following section describes the results of the measurements and separation of signals for individual fingers[12], introduces a system that applies the results, and shows our future research plans.

## 2.1 Identification of EMG finger motion patterns

The extensors and flexors of the palm and forearm control finger motions. We separated the 16 channels of surface electromyogram into more than 10 movements: e.g., extension/flexion of fingers and grasp/release of hand. The electrodes were relatively carelessly placed in positions other than right above the bones on a forearm.

After the subject relaxed the muscle fibers of the arms, he/she was asked to extend and flex the fingers from the thumb through the little finger and to grasp and open his/her hand, as if performing a natural movement in daily life. The surface electromyogram was recorded through a low-pass filter with a cutoff frequency of 250 Hz, with a sampling rate of 1kHz and 12-bit A/D conversion as shown in Fig.1.

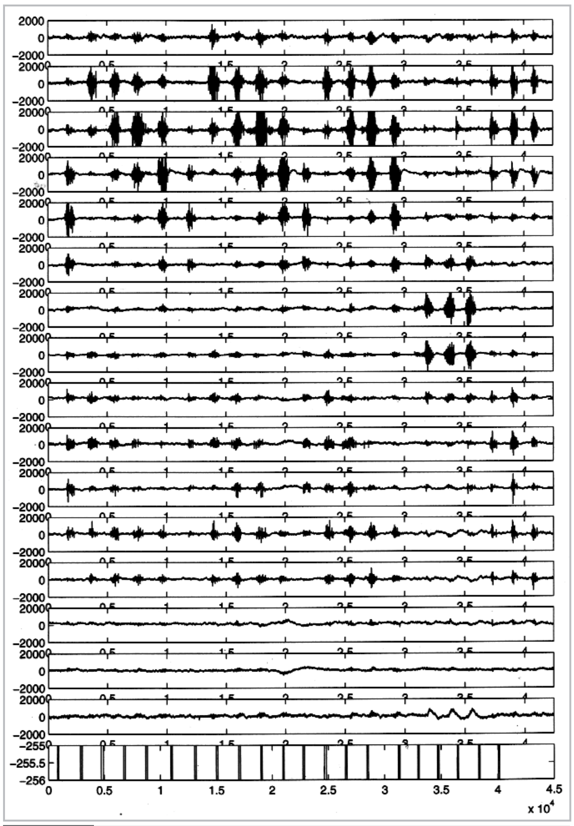

**Fig.1** Recording of electromyograms during the extending and flexing of fingers.

The vertical axis represents the amplitude and the horizontal axis the number of samples (time). The marks at the bottom show the starting times of each finger extension or flexion.

The extraction of a distribution of signals among the various channels was sufficient for our purpose to identify finger motions. Thus, noise was removed and the data was then smoothed by the use of a filter and rectifier. We used a high-pass filter with a cutoff frequency of 20Hz and a low-pass filter with a cutoff frequency of 2.5Hz (commonly used for processing electromyograms[18]).

An independent component analysis (ICA) was performed on the resulting data to identify relevant patterns. ICA is a recently developed method that uses high-order statistics to separate a signal into statistically independent components[19][20]. This technique makes it possible to separate multi-channel signals into independent components when these signals are observed as a linear superposition of statistically independent signals with a non-Gaussian distribution, such as biological signals. In statistical terms, this separation is a semi-parametric estimation that estimates the parameters of a mixing matrix without requiring detailed knowledge of the distribution of independent components.

The data in the above experiment consisted of separate measurements of finger motions. Thus, no signals were mixed, and ICA may seem unnecessary. Simultaneous finger motions produce a surface electromyogram that cannot be expressed as a linear superposition of independent components. Therefore, ICA cannot be used to extract such motions. On the other hand, when ignoring the temporal structure, the probability density distribution of the signals nearly satisfies the assumption of ICA. Hence, although separation of the combined motions is unfeasible, we found that ICA is sufficient for the purpose of separating individual finger motions. Another useful aspect of this analysis is that it allows finger motions to be separated and identified even without knowledge of when the fingers moved.

Fig.2 indicates the results of ICA and plots all separated components (sorted in the order of movement). This figure indicates that the first through fifth components were almost perfectly separated for extension, and the sixth component for grasp, respectively. The action of opening the entire palm was separated into two major components, while the actual operation consisted of three movements. This seems to indicate that the three actions were not identical. The eighth and later components were slightly related to finger motions, but more to fluctuation of movements and external noise. The estimation of the mixing matrix revealed that the obtained spatial distribution of each component in each channel was consistent with the results of physiological studies.

## 2.2 Applications

The above analyses of finger motions are applied and described below. (Reference[21] provides movement pictures and other information.)

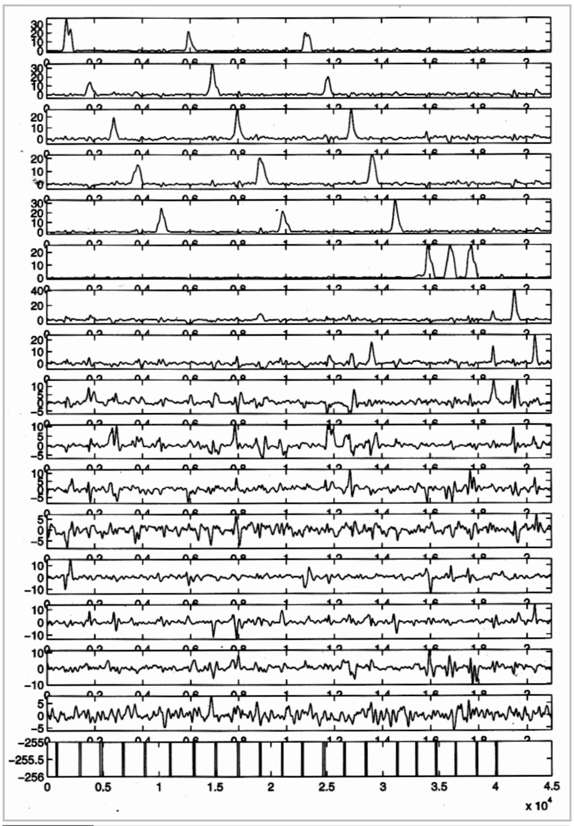

**Fig.2** *Analyzed independent components.*

The marks at the bottom show the starting times of fingers' motions.

Simple mapping of separated and identified finger motions may allow various applications. We applied the above analytical results to:

- the playing of a virtual piano with a musical note allotted to each finger;
- a vocalization interface using a combination of vowels, consonants, and execution; and
- a virtual hand.

The first two applications used finger motions as on and off signals, while in the last application the virtual hands moved according to the intensity of a related signal. The eleven types of movement (i.e., flexion and extension of five fingers, and a grasping motion) were analyzed separately. Although there was slight interference between fingers, finger motions were reproduced to a satisfactory degree.

### 2.3 Application to amputees who have lost their forearms

The above system was applied to an amputee who has lost her forearm. As shown in Fig.3, electrodes were attached to the remaining part of the forearm of an amputee subject who lost her forearm three years ago. When we asked her to move her fingers, she succeeded in separately moving each “virtual finger” presented by the system (Fig.3).

She said she had a phantom hand with movable fingers when seeing the virtual fingers. At the time of the experiment, she had worn an electromyogram artificial arm capable of holding an object for about half a year. She continued to have the sensation of possessing the hand that had been amputated. The phantom hand was like a glove of which four fingers are fixed as a unit, similar to those of the artificial arm. She did not feel like she had separate fingers when she used the artificial arm.

Of course, the reactions of subjects varied, and the above results are not necessarily indicative of the reactions of other subjects, and we are now collecting data from other amputees. Nonetheless, it is very interesting that a person who has lost her forearm may still move the muscle fibers remaining in her forearms to generate an electromyogram pattern that is able to move individual virtual fingers. Currently we are conducting additional experiments in cooperation with Hyogo Assistive Technology Research and Design Institute(Hyogo ASSISTECH) in Kobe.

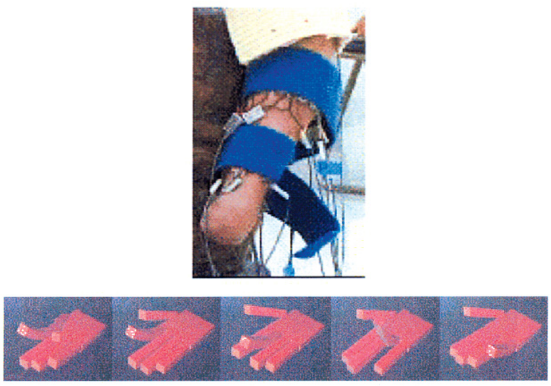

**Fig.3** *Recognition of finger motions by an amputee who lost her forearm.*

Above: wearing electrodes. Below: showing finger motions using a virtual hand.

### 2.4 Future work

We are planning to develop the present research as follows:

#### *2.4.1 Application of the present system for persons who have lost their forearms*

We worked with Hyogo ASSISTECH to determine the extent to which handicapped persons are able to intentionally generate a finger motion pattern. When a person who has lost his/her forearms should still be able to move the muscle fibers that once controlled his/her fingers, he/she can receive visual feedback and aural feedback. According to a recent study[22] on the reconstruction of physical senses in neurology, such feedback may help reduce or eliminate the sensations of pain associated with phantom limbs. We also expect to apply the current system to the QOL of persons who have lost their forearms. This system may be able to provide “virtual hands” that enable subjects to access computers and to express themselves by playing specially designed musical instruments, for example.

#### *2.4.2 Estimation of motor units using multiple channels*

The present system is able to separate and identify finger motions. Identification of simultaneous finger motions of two fingers or more is a meaningful subject of future study. We plan to conduct basic research to identify muscle fibers that are controlled by a motor nerve fiber[23] by using 64-channel electrodes to analyze measured fine electric pulses and phase information. This is similar to the CT scan technique, and a preliminary analysis has already started in cooperation with Kotani Laboratory, Department of Computer and Systems Engineering, Faculty of Engineering, Kobe University.

## 3 Cognitive mechanisms in preverbal communication

Nursing and housekeeping robots could

become important members of any family in the near future. How will such robots naturally communicate and interact with their human interlocutors ? What should be done to involve them in human society as social beings? In this study, we considered the development of preverbal communication (e.g., pointing, gestures, and other types of physical communication), and develop design principles for human friendly communication systems.

### 3.1 Infanoid as a research platform

Before describing the developmental model of preverbal communication, we introduce Infanoid[9][10], an infant robot. Infanoid serves as a research platform for cognitively modeling the development of the ability for human communication. As shown in Fig.4, Infanoid is a humanoid upper torso. At a height of 480 mm from the table top, it is similar in size to the upper torso of a three-year old infant. Its body has 23 degrees of freedom (axes of movement).

Infanoid has two eyes, each of which has two video cameras with a wide-angle lens (offering a horizontal viewing field of 120°) and with a telephoto lens (offering a horizontal viewing field of 25°). The eyes can rotate up/downward and left/rightward for saccade and smooth pursuit of visual targets. Images taken by the video cameras are processed by a massively parallel image processing system that tracks the human faces and facial features of people and that identifies objects by their color, depth, and shape. Infanoid has a speech processing module that allows it to vocalize babbling and articulated words with intonations. It can also move its upper and lower lips synchronizing with the vocalized phonemes.

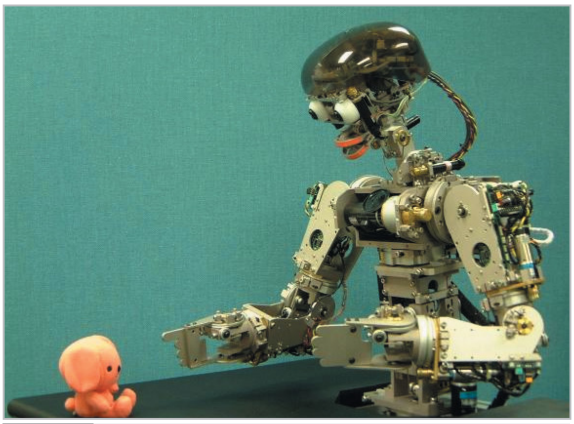

**Fig.4** Infanoid, an infant robot

Currently, Infanoid is able to:

(1) visually track a human face and the orientation of the face,
(2) visually track a specific object (e.g. toy),
(3) alternate its gaze between the human face and the object, and
(4) vocalize babbling.

In the future, Infanoid will be capable of:

(5) Searching in the direction of the gaze, and
(6) partial imitation of voices (echoing using limited vocalizable phonemes).

### 3.2 Joint attention and indirect experiences

A neonate can control the behavior of another person to a certain degree through crying, smiling, and other nonverbal gestures. At first, crying helps a neonate to obtain food from the caregiver, and to carry him/her in caregiver's arms. Then, the neonate may start pointing to indicate what he/she wants. Eventually, the neonate becomes capable of speech and participates in more sophisticated social interaction.

Recent studies in developmental psychology[24]~[26] have revealed that joint attention plays an important role in the development of infants' communication. Joint attention involves directing attention to an object to which another person is paying attention. As shown in Figs.5 and 6, to create joint attention with the caregiver, the following two processes are required:

(1) capturing the direction of caregiver's attention from the gaze, face orientation and pointing,
(2) identifying the object the caregiver is paying attention to.

What is the role of joint attention? Joint attention allows an infant or robot to be able to observe and understand the behavior of anoth-

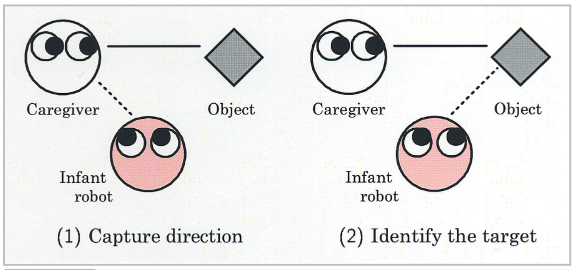


**Fig.5** *Process of joint attention*

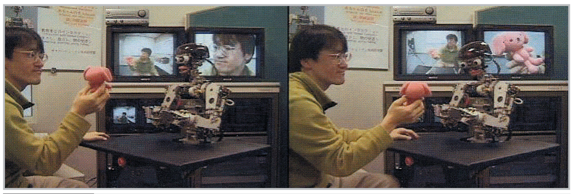

**Fig.6** *Joint attention with Infanoid*

er person[8]. Suppose that the caregiver is interacting with the object in the environment, as shown in Fig.7. The infant or robot will be able to estimate the sensory input *i* that the caregiver is perceiving from the environment. Since they are both focused on the same object, their sensory inputs, *i* and *i'*, are nearly identical. When reading the direction of the caregiver's attention, the infant observes various motor outputs *o* (e.g., facial expression, vocalization, behavior) that the caregiver gives on the object.

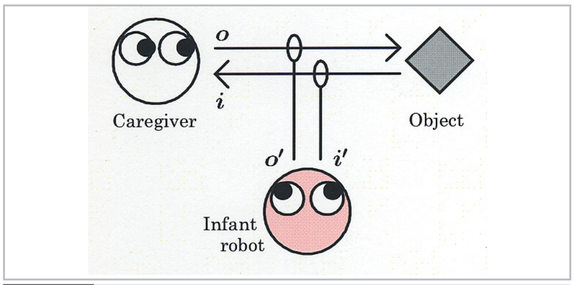


**Fig.7** *Observation of the sensory input and motor output of another person*

It should be noted that an infant's observation of the motor output *o* is only exteroceptive (mostly, visual). To imitate another person's behavior, the infant needs a mapping process for converting this exteroceptive information *o'*, into a proprioceptive image of the motor action $\mu(o')$. This process is considered to develop over time from innate primordial imitation[27][28] such as the mimicking of facial expressions and response facilitation, through the processes of imitating the caregiver and playing with the parts of its own body (for example, hand regard).

Through joint attention, an infant takes in the sensory input *i* as *i'*, and takes the motor output *o* of the other person as exteroceptive information *o'*, and then, converts this image into an image of the motor action $\mu(o')$. This is a virtual experience of the other person's behavior <*i*, *o*> as <*i'*, $\mu(o')$>, or an indirect experience[8]. Imitation is a reconstruction of this <*i'*, $\mu(o')$>.

### 3.3 Social development by indirect experience

Indirect experience and imitation provide example data (both positive and negative examples) for identifying various situations, and learning how other persons react in such situations. This learning makes it possible to predict the type of action another person will take (e.g., dialing) when the person is confronted with an object (e.g., a telephone). When a person is doing something (e.g., waving his/her hand good-bye), an infant can identify the intended target (e.g., other party out of the infant's sight) of the caregiver's action. If an infant wants a person to take some action, he/she has only to convey a sensory input that induces the desired action in the person.

An indirect experience makes it possible to learn the pattern of an action that is exogenously elicited. Such action alone is insufficient for a baby to ask the caregiver to give it a piece of candy unless the infant pantomimes the eating of a piece of candy. What should he/she do to voluntarily eat the candy, or to earn a reward by voluntarily working on the environment (object)? The learning process likely consists of the execution of a motor output, followed by a random response (operant response). The infant then evaluates the result of its motor output (or its variation) based on sensory information (e.g., pleasure or displeasure), and then uses positive sensory information as a reinforcer to continue its learning process.

### 3.4 Exploration of the social environment

A caregiver can be an object (like the piece of candy in the above example) for an explorative activity. As shown in Fig.8, when an infant (or a robot) presents a variation of an existing repertoire of actions or a random response, the caregiver interprets the social meaning of the presentation and responds accordingly to the infant's actions. If the presentation is socially appropriate, he/she will obtain a reward (attention, delivery of an object). If it is a socially inappropriate or meaningless presentation, he/she will receive “punishments” (e.g., by disregard or reprimand).

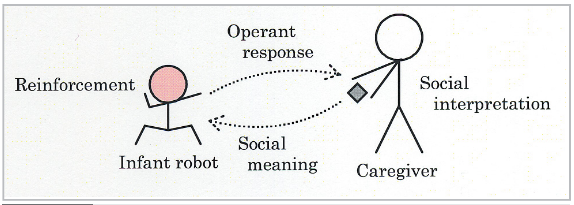


**Fig.8** Social exploration through a caregiver

The above explorative activity results in the development of “intentionality”[10]. For example, suppose that an infant utters a nonsense word (babble). Upon hearing him/her, the caregiver picks up and hands the infant a toy. As a result of the original action, the infant has received an unexpected reward. This series of actions (“utterance results in obtaining a toy”) are reinforced by obtaining a reward. After repeating this trial several times, one type of sound becomes connected to one toy, and another sound to another toy. Eventually, the infant acquires the ability to communicate which toy he/she wants. In other words, an intentional behavior that produces an effect becomes associated with a means of attaining a desired objective.

Indirect experiences (imitation) help the infant learn and use socially meaningful behaviors (sometimes with unintended results) in accordance with feedback from the caregiver[29]. This process is considered to extend in such a way that a random fluctuation is incrementally given to the “seeds” in a space of possible behaviors, behavior is evaluated in terms of the caregiver’s reaction, and then a socially meaningful gamut of behavior is explored. This may not be a binary class having a definite contour, but a fuzzy class.

Such exploration of social behavior helps infants acquire knowledge of shared communication protocols (e.g., gestures, language)[30]. Once a certain level of communication ability is acquired, it may be used to explore more sophisticated activities. This mechanism seems to have boosted the human communication ability to a uniquely high level compared with other species.

### 3.5 Future work

The present research consists of two complementary studies: a psychological study for constructing a developmental model of communication; and a robotic study designed to prove this model using an infant robot, Infanoid, as a research platform. Past studies on robotics focused on learning and not development. Developmental psychology is helpful in the observation of infants but also requires some supplementary methods before it can be used to conduct manipulatable (particularly, invasively manipulatable) experiments. Thus, the present study will provide a new point of view and a new experimental paradigm.

We plan to extend the research to bridge the gap between developmental psychology and robotics. Additional studies should examine the abilities of both normal infants and infants with developmental disorders[26][31] for identifying innate ability as a precondition for the development of effective communication, and specifying the most appropriate developmental environment for such development. The present Infanoid does not embody all the sensorimotor modalities[32] that a real infant has. We plan to increase Infanoid’s ability to interact with physical and social environments like a human being does.

# 4 Nonverbal information in interaction

Communicating in the real world often involves face-to-face interactions. Of course, we sometimes use non-visual forms of communication, such as telephones. When greater intimacy is desired or when important information is to be conveyed, many people prefer communicating by telephone rather than by writing, just as many people prefer a face-to-face discussion to a telephone conversation. This indicates that in communication, linguistic information is less important than paralinguistic information accompanying the words, (e.g., the tone, frequency, volume, and speed of speech), as well as non-linguistic information (e.g., facial expressions and gestures)[33].

## 4.1 Determining the context of a conversation based on head movements

In order to create high-modality for dialogues, we examined the effects of movements of the upper part of a human body (particularly head movements) on the liveliness of the dialogues and mutual understanding, considering the movement as one type of nonverbal information. There are two flows for creating high-modality for dialogues: the cognition and conveying of information.

First, we sought to determine the process of recognizing information included in a high-modality dialogue. Thus, while two subjects were talking with each other, we recorded linguistic information and head movements. Conventional methods of such recording call for a tilted video camera to be placed above the eyes of a subject, as shown in Fig.9. As this camera does not meet with the eyes of the subject, the camera gives physical information different from that gained by the interlocutor who is in face-to-face communication. Correcting the difference is possible but the correction may possibly contain errors. Thus, conventional methods are not suitable for obtaining precise information that the subjects obtain when their eyes meet.

In this study, we applied a two-way mirror

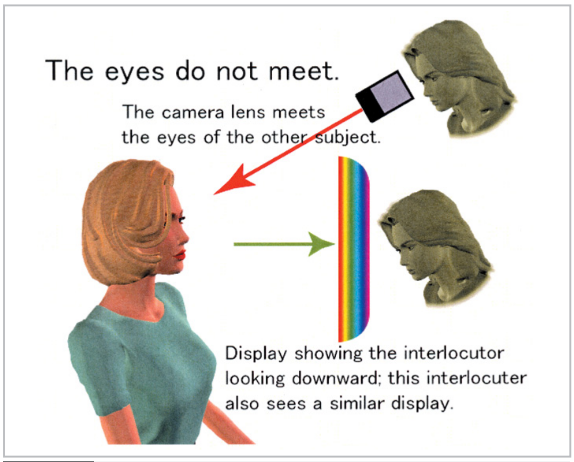


*Fig.9* *Impossibility of eye contact in conventional methods*

to the dialogue recording system to avoid the problem of the conventional methods, as shown in Fig.10. This mirror allowed the camera to meet subject's eyes right in front of the subject. Extra video cameras were placed such that the subjects could be seen directly from the side.

In the dialogues, subjects solved prescribed tasks. The dialogues were video recorded, providing (1) linguistic information originating from normal voices, (2) paralinguistic information, and (3) non-linguistic information consisting of eye movements, facial expressions, and head movements.

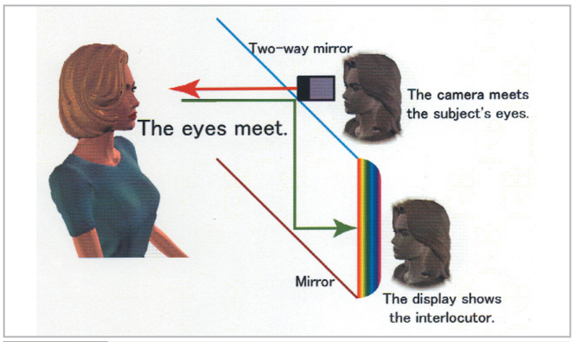


*Fig.10* *Eye contact by use of a two-way mirror*

We are currently applying image processing to records obtained using the above method, in order to improve technological recognition of non-linguistic information. The goal is to evaluate hard-to-define situations, such as "getting livelier" and "sympathy," in real-time without linguistics information originated from dialogues. This situation seems similar to that when we enter an area where unknown language is spoken or when one meets infants who have not completed language acquisition. Since this method does not use information directly connected to the contents of the dialogue, it may give an index that shows differences in dialogue culture, independent of linguistic languages.

We comprehensively evaluated not only data on the volume and pitch of voices in dialogues but also images originating from nonlinguistic information. We intend to develop a method of recognizing hard-to-define situations by using nonverbal information in a dialogue, by sensing factors such as smiles, collaborative completions, collaborative nodding, and eye contact that have tended to be ignored in previous linguistics studies.

### 4.2 Future work

We intend to add a nonverbal information recognition module to an embodied system such as a robot so that the system may have a cognitive cue for determining the mental and emotional state of a speaker from nonverbal information. When the robot sends out nonverbal information, this module may be used to obtain feedback for predicting the influence on the "field" and identifying the state of the "field" containing the robot. This means that a robot may be able to control the "field" of dialogue, that is, to intentionally make the "field" livelier or less lively.

We will also consider the possibility of applying this method to video compression to enable two-way communication with a high modality. Such a compression would be different from the popular types of video compression (for example, MPEG[34]~[36]), giving a priority to the liveliness of the "field" rather than motion in compression.

## 5 Conclusions

We conducted in a study of embodied communications as a new project at Keihanna Human Info-Communications Research Center. Our embodied communication system may be acknowledged as an intentional being and as a social being equivalent to a human being with respect to communication. Such embodiments make it possible for the system to understand physical and psychological situations simultaneously, thereby allowing it to interact effectively with human beings. We should promote our studies so that the communication systems can participate in society, and can help to improve our quality-of-life.

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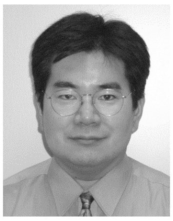

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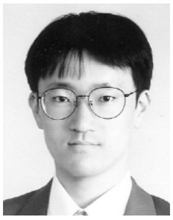

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