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TOWARD SOCIAL MECHANISMS OF ANDROID SCIENCE A COGSCI 2005 WORKSHOP

Android Science
- Toward a new cross-interdisciplinary framework -

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Abstract

In the development of humanoids, both the appearance and behavior of the robots are significant issues. However, designing the robot's appearance, especially to give it a humanoid one, was always a role of the industrial designer. To tackle the problem of appearance and behavior, two approaches are necessary: one from robotics and the other from cognitive science. The approach from robotics tries to build very humanlike robots based on knowledge from cognitive science. The approach from cognitive science uses the robot for verifying hypotheses for understanding humans. We call this cross- interdisciplinary framework *android science*. This conceptual paper introduces the developed androids and states the key issues in android science.

1. Introduction

Intelligence as subjective phenomena

How can we define intelligence? This fundamental question motivates researchers in artificial intelligence and robotics. Previous works in artificial intelligence considered functions of memory and prediction to realize the intelligence of artificial systems. After the big wave of artificial intelligence in the 1980's and 1990's, researchers focused on the importance of embodiment and started to use robots. The *behavior-based system* proposed by Brooks [Brooks 91] was a trigger for this new wave. This means the main focus on artificial intelligence and robotics has changed from an internal mechanism to interaction with the environment.

On the other hand, there are also two ideas in cognitive science. One is to focus on the internal mechanism for understanding human intelligent behaviors, while the other focuses on the interactions among people. This latter approach is studied in the framework of *distributed cognition* [Hollan 00]. The idea of distributed cognition has similar aspects to the behavior-based system. The common concept is to understand intelligence through human-human or human-robot interactions.

This paper also follows the ideas of the behavior-based systems and distributed cognition. Because intelligence is a subjective phenomena, it is therefore important to implement rich interactive behaviors with the robot. The author believes the development of rich interactions among robots will provide hints of principles of communication systems, with the design methodology of intelligent robots then being derived from those principles.

Constructive approach in robotics

First we have the question of how to develop the robots. There are explicit evaluation criteria for robot navigation such as speed, precision, etc. On the other hand, our purpose is also to develop interactive robots. If we have enough knowledge of humans, we may have explicit evaluation criteria.

However this knowledge is not sufficient to provide a top-down design; instead the potential approach is rather bottom-up. By utilizing available sensors and actuators, we can design the behaviors of a robot and then decide the execution rules among those behaviors. While doing this developing, we also evaluate the robot's performance and modify the behaviors and execution rules. This bottom-up approach is called the *constructive approach* [Ishiguro 02]

In the constructive approach, interactions between a robot and a human are often evaluated and analyzed through discussions with cognitive scientists and psychologists, with the robot then being improved by the knowledge obtained through the discussions.

Appearance and behavior

In the evaluation, the performance measures are subjective impression [kanda 01] of human subjects who interact with the robot and their unconscious reactions, such as synchronized human behaviors in the interactions and eye movements [Itakura 04a].

Obviously, both the appearance and behavior of the robots are important factors in this evaluation. There are many technical reports that compare robots with different behaviors. However nobody has focused on appearance in the previous robotics. There many empirical discussions on very simplified static robots, say dolls. Designing the robot's appearance, especially to give it a humanoid one, was always a role of the industrial designer. However we consider this to be a serious problem for developing and evaluating interactive robots. Appearance and behavior are tightly coupled with both each other and these problems, as the results of evaluation change with appearance. In our previous work, we developed several humanoids for communicating with people [Ishiguro 01b, 02, Kanda 04], as shown in Figure 1. We empirically know the effect of appearance is as significant as behaviors in communication. Human brain functions that recognize people support our empirical knowledge.

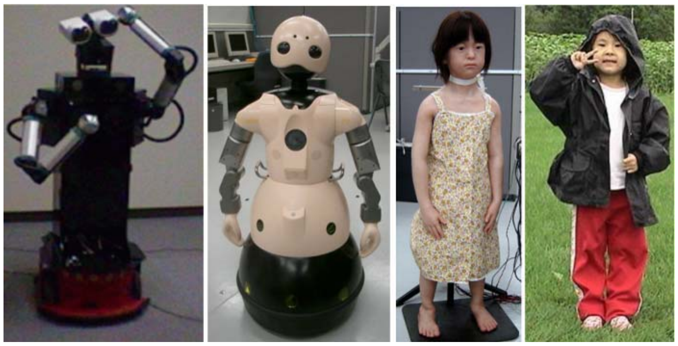

Figure 1: From humanoids to androids. The first robot (the left end) is Robovie II developed by ATR Intelligent Robotics and Communications Laboratories. The second is Wakamaru developed by Mitsubishi Heavy Industry Co. Ltd. The third is a child android, while the fourth is the master of the child android.

Android Science

To tackle the problem of appearance and behavior, two approaches are necessary: one from robotics and the other from cognitive science. The approach from robotics tries to build very humanlike robots based on knowledge from cognitive science. The approach from cognitive science uses the robot for verifying hypotheses for understanding humans. We call this cross-interdisciplinary framework *android science*.

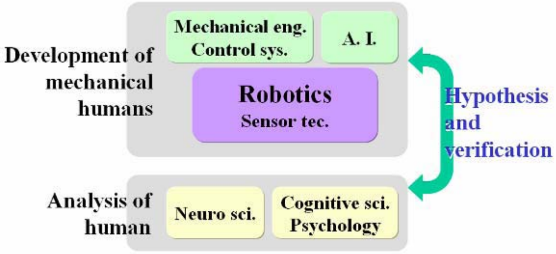

Figure 2: The framework of android science

Previous robotics research also used knowledge of cognitive science while research in cognitive science utilized robots. However the contribution from robotics to cognitive science was not enough as robot-like robots were not sufficient as tools of cognitive science, because appearance and behavior cannot be separately handled. We expect this problem to be solved by using an android that has an identical appearance to a human. Robotics research utilizing hints from cognitive science also has a similar problem as it is difficult to clearly recognize whether the hints are given for just robot behaviors isolated from their appearance or for robots that have both the appearance and the behavior.

In the framework of android science, androids enable us to directly exchange knowledge between the development of androids in engineering and the understanding of humans in cognitive science.

2. Development of androids

Very humanlike appearance

The main difference between robot-like robots and androids is appearance. The appearance of an android is realized by making a copy of an existing person.

The process is as follows. First, human-body parts molds are made from a real human with the shape memory form used by dentists. Then plaster human-parts models are made by using the molds. A full-body model is obtained by connecting the plaster models. Again, a mold for the full-body model is made from the plaster model and a clay model is made by using the mold. Here, professionals of formative art modify the clay model without losing the detailed texture. The human model loses its form in the first molding process because human skin is soft. After the modification, a plaster full-body mold is made from the modified clay model, and then a silicon full-body model is made from the plaster mold. This silicon model is maintained as a master model.

Using the master model, silicon skin for the full body is made. The thickness of the silicon skin is 5mm in our trial manufacture. The mechanical parts, motors and sensors are covered with polyurethane and the silicon skin. Figure 3 shows the silicon skin, inside mechanisms and head part. Figure 4 shows the finished product of a child android made by painting colors on the silicon skin. As shown in the figure, the details are recreated very well so they cannot be distinguished from photographs of the real child.

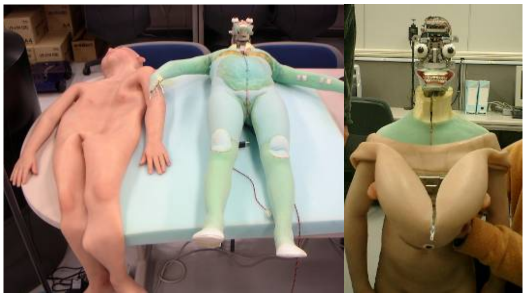

Figure 3: The silicon skin and inside mechanisms

Figure 4: Child android

The technology to recreating a human as an android has been accomplished to some extent; however it has not yet been perfected. The difficulties are:

- Details of the wetness of the eyes
- More flexible and robust skin material

The most sensitive part for human subjects is the eye. When confronted with a human face, a human first looks at the eyes. Although the android has a mechanism for blinking and the eyeballs are perfect copies, we are aware of the differences from a real human. As the wet surface of the eye and the outer corners are difficult to recreate with silicon, more improvement is required in this area.

The current silicon used in this trial manufacturing is sufficient for recreating the texture of the skin. However, it loses flexibility after one or two years and its elasticity is insufficient for large joint movements.

Mechanisms for humanlike movements and reactions

Very humanlike movement is another important factor for developing androids. For realizing humanlike movement, we developed an adult android because the child android is too small. Figure 5 shows this developed android. The android has 42 air actuators for the upper torso except fingers. We decided the positions of the actuators by analyzing movements of a real human using a precise 3D motion tracker. The actuators can represent unconscious movements of the chest from breathing in addition to conscious large movements of the head and arms. Furthermore, the android has a function for generating facial expression that is important for interactions with humans. Figure 6 shows several examples of facial expression. For this purpose, the android uses 13 of the 42 actuators.

The air actuator has several merits. First, it is very silent, much like a human. DC servomotors that require several reduction gears make un-humanlike noise. Second, the reaction of the android as against external force becomes very natural with the air dumper. If we use DC servomotors with reduction gears, they need sophisticated compliance control. This is also important for realizing safe interactions with the android.

On the other hand, the weakness of the air actuators is they require a large and powerful air compressor. Because of the need for an air compressor, the current android model cannot walk. For wide applications, we need to develop new electric actuators that have similar specs to the air actuators.

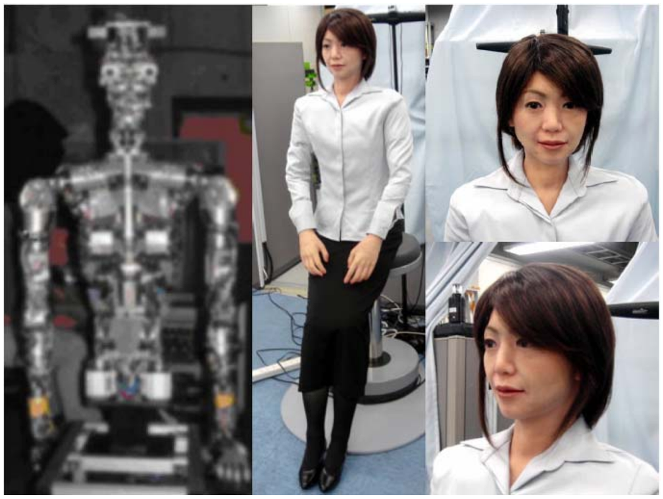

Figure 5: Adult android developed in cooperation with Kokoro Co. Ltd.

Figure 6: Facial expressions of the android

The next issue is how to control the 42 air servo actuators for realizing very humanlike movements. The simplest approach is to directly send angular information to each joint by using a simple user interface termed a *motion editor*. However we need to specify 42 angles for creating a posture, which takes a long time. Therefore we added a function to generate smooth motions based on sinusoidal signals. This is the same idea as Perlin noise [Perlin 95] used in computer graphics. This function helps especially well in making partial movements; however it is still time-consuming.

In addition to this problem, another difficulty is that the skin movement does not simply correspond to the joint movement. For example, the android has more than five actuators around the shoulder for humanlike shoulder movements, with the skin moving and stretching according to the actuator motions. For solving this problem, a mapping table was required that correlates the surface movement to the actuator motions.

Our idea for solving this problem is to train a neural network. The neural network memorizes a mapping between actuator command patterns and marker 3D positions based on a large number of examples of android postures. Of course this is still not sufficient. Our current implementation is for position control based on a closed loop position control of each actuator, but it is not easy to increase the feedback gain because of the dumper of the air actuator. In other words, the speed of android movement is limited. For realizing more quick and humanlike behavior, speed and torque controls are required in our future study.

Toward very humanlike movement

The next step after obtaining the mapping between the surface movements and actuators is implementing humanlike motions in the android. A straightforward approach for this challenge is to imitate real human motions in cooperation with the master of the android. By attaching markers of the precise 3D motion tracker on both the android and the master as shown in Figure 6, the android can automatically follow human motions.

We have not yet finished this work, but interesting issues have arisen with respect to this imitation. The imitation by the android means representation of complicated human shape and motions in the parameter space of the actuators. Although the number of the actuators is not small, the effect of data-size reduction is significant. Therefore we may find important properties of human body movements by analyzing the parameter space. More concretely, we expect to have a hierarchical representation of human body movements that consists of two or more layers, such as small unconscious movements and large conscious movements. With this hierarchical representation, we can have more flexibility in android behavior control.

Figure 6: Marker positions on the master (right) and android (left)

Humanlike perception

The android requires humanlike perceptual abilities in addition to a humanlike appearance and movements. This problem has been tackled in computer vision and pattern recognition in rather controlled environments. However, the problem becomes seriously difficult when applied to the robot in other situations, as vision and audition become unstable and noisy.

Ubiquitous/distributed sensor systems solve this problem. The idea is to recognize the environment and human activities by using many distributed cameras, microphones, infrared motion sensors, floor sensors and ID tag readers in the environment. We have developed distributed vision systems [Ishiguro 97] and distributed audition systems [Ikeda 04] in our previous work. For solving this problem this work must be integrated and extended. Figure 7 shows the current sensor network installed in our laboratory. The omnidirectional cameras observe humans from multiple viewing points and robustly recognize their behaviors [Ishiguro 01a]. The microphones catch human voice by forming virtual sound beams. The floor sensors that cover the entire space of the laboratory reliably detect footprints of humans.

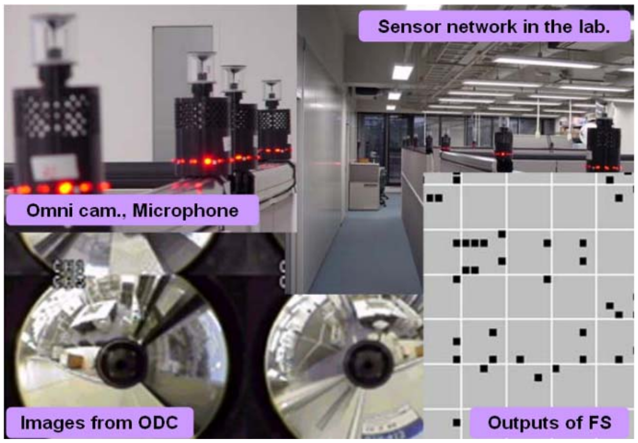

Figure 7: Distributed sensor system

The only sensors that should be installed on the robot are skin sensors. The soft and sensitive skin sensors are important particularly for interactive robots. However, there has not been much work in this area in previous robotics. We are now focusing on its importance in developing original sensors. Our sensors are made by combining silicon skin and Piezo films as shown in Figure 8. This sensor detects pressure by bending the Piezo films. Further, it can detect very nearby human presence from static electricity by increasing the sensitivity. That is, it can perceive a sign a human being is there.

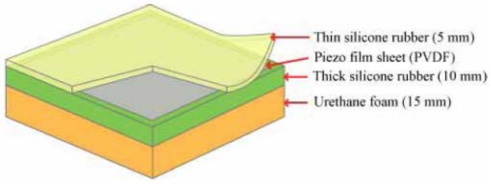

Figure 8: Skin sensor.

These technologies for very humanlike appearance, behavior and perception enable us to develop androids.

3. Cognitive studies using androids

Total Turing test

As discussed in the Introduction, android science has two aspects, the engineering approach and the scientific approach. The most vivid experiment where the two approaches meet is the *total Turing test*. The original was devised to evaluate the intelligence of computers under the assumption that mental capacities could be abstracted from embodiment [Turing 50, Harnad 91, 00]. The approach invoked many questions about the nature of intelligence [Harnad 90]. We consider intelligence as subjective phenomena among humans or between humans and robots. Obviously, the original Turing test does not cover the concept of total intelligence. In contrast, the android enables us to evaluate total intelligence.

As did the original Turing test, the Total Turing test uses a time competition. We have checked how many people in preliminary experiments do not become aware within 2 sec. that they are dealing with an android. Figure 9 displays the scene. A task is given to the subject to find the colors of the cloth. The screen between the android and the subject opens for 2 sec. The subject then identifies the color. At the same time, the subject is asked whether he/she became aware the other is an android. We have prepared two types of android, one a static android and the other an android with the micro movements we call unconscious movements. Figure 10 shows an example of unconscious movements. Because a human does not freeze, he/she is always slightly moving even when not doing anything, such as just sitting on a chair. The android shown in Figure 10 has such micro movements.

Figure 9: Total Turing test

As the result of the experiment with 20 subjects, 70% of the subjects did not become aware they were dealing with an android when the android had micro movements, but 70% became aware with the static android. This result shows the importance of the micro movements for the appearance of humanlike reality.

The 2-second experiment does not mean the android has passed the total Turing test. Nevertheless, it shows significant possibilities for the android itself and for cross-interdisciplinary studies between engineering and cognitive science.

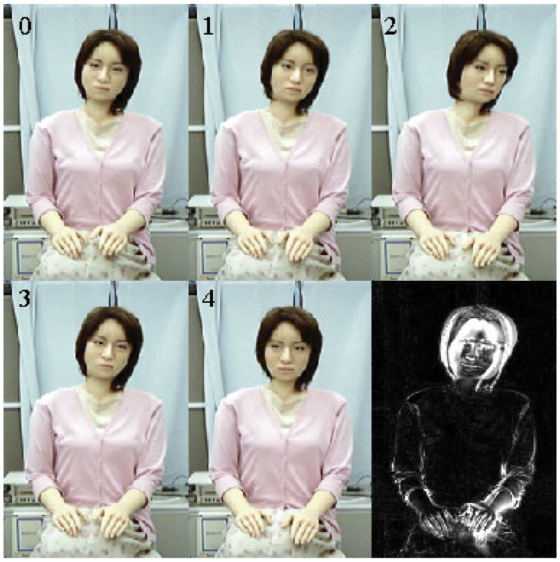

Figure 9: Micro movements of the android. Five snapshots and the movements (bottom right)

Uncanny valley

Why do 30% of the subjects become aware of the android? What happens if the time is longer than 2 sec.? In the experiment, the subjects felt a certain strangeness about the android's movements and appearance. Mori [Mori 70] predicted that as robots appear more human, they seem more familiar, until a point is reached at which subtle imperfections create a sensation of strangeness as shown in Figure 10. He referred to this as the *uncanny valley*.

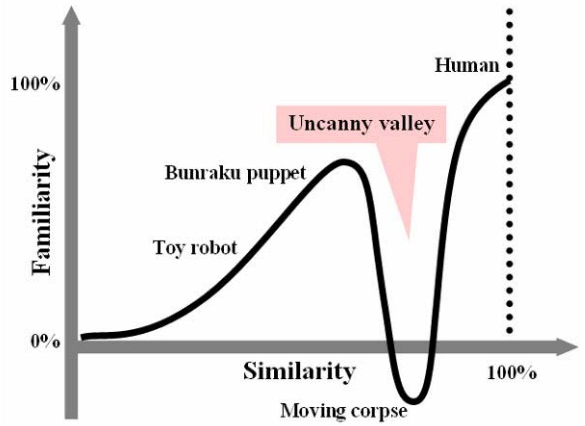

Figure 10: Uncanny valley

Extension of the uncanny valley

Why does this uncanny valley exist? We have two hypotheses:

- If its appearance is very humanlike, the subject attempts to understand the android as being human. Therefore the subtle difference creates a strong strangeness as the uncanny valley.
- Humans expect balance between appearance and behaviors when they recognize creatures.

The second hypothesis means familiarity increases for well-balanced appearance and behavior. We refer to this as the *synergy effect*. For example, a robot should have robot-like behaviors and a human should have humanlike behaviors [Chaminade 01]. This differs from the uncanny valley because humans do not have sensitive mental models for recognizing robots and other toys.

Based on these hypotheses, we have extended the graph depicted by Mori as shown in Figure 11, which was obtained by fusing the uncanny valley provided by the first hypothesis with the synergy effect provided by the second hypothesis. This 3D graph is not exact, but rather conceptual as is Mori's graph. Nevertheless it is still a significant guide for our research. Our important role is to verify the structure of the graph through development of androids and cognitive experiments with them and obtain a more precise graph.

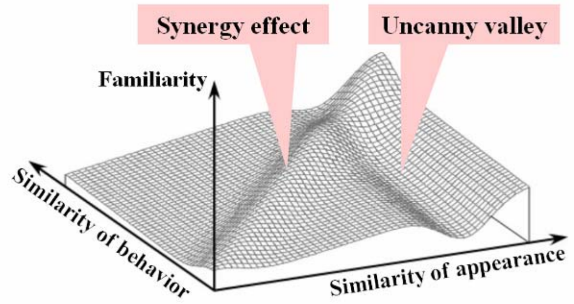

Figure 11: The extended uncanny valley

Age-dependent uncanny valley

There is also an age-dependent relationship [Itakura 04b]. One-year-old babies were attracted to the child android and were unperturbed by even jerky, robotic movements. However children between the ages of three and five were afraid of the android and refused to face it. We found this phenomenon with preliminary experiment using infants.

We consider the reasons to be as follows. If the baby's model of others is not so well-developed, the android may be able to pass itself off as human. Adults know the android is not human, so they do not expect it to fit closely a human model. However young children seem to be in the middle ground of applying a human model to the android, but finding it mismatches. This is a kind of uncanny valley. We expect to learn more about the developmental process of human recognition models of infants by verifying this age-dependent uncanny valley.

Evaluation of the familiarity

To identify the graphs of the extended uncanny valley and the age-dependent uncanny valley, proper evaluation criteria are required.

However it is not so easy to make comparisons with previous robotics where speed and precision were the evaluation criteria. For interactive robots, we have to evaluate human-robot interactions.

The familiarity appears as subjective opinions of the subjects. The standard method is the SD method used in psychology for evaluating the interaction. However control of the subjects is not easy, so methods that are more objective are preferred. One approach is to find a correspondence between the subjective impression and unconscious reactions of the subjects. If subjects have good impressions of the robot, their behavior synchronizes to the robot behavior and they have frequent eye contact. We have developed a method using a precise 3D motion tracker as in our previous work [Kanda 03] and applied it to the evaluation of robot-like robots. This method also works for the androids.

A more objective method is brain imaging by using functional MRI, opt-topography, electro-encephalograms, or magneto -encephalograms. The most promising approach is opt-topography because it does not require magnetic-shielded or electric-shielded rooms. Although the technology is not yet well-established, it will be a key for evaluation of human-robot interaction.

Conscious and unconscious recognition

Another important viewing point for the evaluation criteria is whether it is conscious or unconscious. The SD method evaluates conscious recognition of the subjects. In contrast, our previous approach evaluates the unconscious recognition. Which is more significant? In the evaluation of an android, this question is difficult to answer. In our experience, the subjects react with it as if it is a human even if they consciously recognize it as an android.

We have observed the eye movement of subjects. Figure 12 shows eye movements between a child and the child android. The child android is very eerie because of the jerky movements. As shown in the figure, the subject cannot keep gazing on the face of the human child and often looks at the upper right corner. In contrast, the subject keeps gazing at the face of the android.

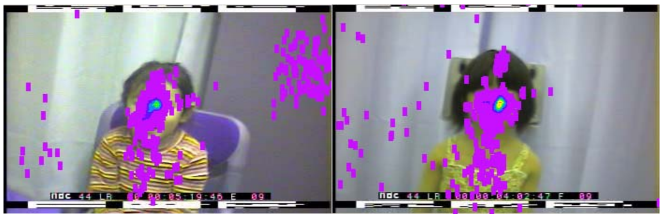

Figure 12: Eye movements as to a human child and the android

Previous works in psychology suggest the following two reasons why the subject cannot keep gazing at the human face.

- Arousal reduction theory: Humans shift their gazing direction to create barriers against external signals for concentration
- Differential cortical activation theory: The eye movements are caused by brain activities.

However these theories do not fit our experiment. We consider there is the third reason as follows

- Social signal theory: The eye movement is a way of representing thinking [McCarthy 01]

We consider a human indicates he/she is social by not continually gazing at the face of another.

Possibility of an android as a human

Then, we have another experiment with the adult android that has humanlike behaviors. After 5 min. habituation, the subject answered questions posed by the android. During the habituation, the android talked while using humanlike body movements. Of course, the subject became aware that it was an android because 5 min. is enough long to observe the details. Figure 13 displays this scene.

Figure 13: The adult android and a subject

We have prepared two tasks for the subject. One is to respond with either lies or the truth to questions posed by the android. The other is to answer seriously both easy and difficult questions posed by the android.

When we humans, tell a lie, it is hard to keep gazing at the face of the person to whom we are lying. For the first task, many subjects shift their gaze when they tell a lie. For the second task, almost all subjects shift their gaze when difficult questions are involved. With respect to the second task, we have compared human-human interaction and human-android interaction. Figure 14 shows the results that subjects shift their gaze in the same way for both humans and androids.

Human-Human interaction

2.2	8.3	12.8
10.8	30.2	6.5
4.4	22.7	2.0

Human-android interaction

3.1	3.1	2.0
4.3	18.2	8.2
20.7	19.9	20.5

Figure 14: Comparison between human-human interaction and human-android interaction. The gazing directions are represented by 9 areas with the numbers representing percentages.

Obviously the subjects consciously recognized the other as an android. However they unconsciously recognized it as a human and dealt with it as a social partner. Although we have discussed evaluation criteria, this finding suggests the evaluation process looks more complicated.

Through the experiment, we have reached at the following hypothesis. If a human unconsciously recognizes the android as a human, he/she will deal with it as a social partner even if he/she consciously recognizes it as a robot. At that time, the mechanical difference is not significant; and the android can naturally interact and attend to human society. Verification of this hypothesis is not easy and will take a long time. However it is an important challenge that contributes to developing deeper research approaches in both robotics and cognitive science.

4. Concluding remarks

This paper has proposed android science as a cross-interdisplinary framework bridging robotics and cognitive science. Android science is expected to be a very fundamental research area where principles of human-human communications and human-robot communications are studied.

The robot system proposed in this paper also has practical possibilities. The robot system integrated with sensor networks has been a recent focus of many researchers, with several countries in Asia and Europe beginning large projects in the area. In Japan, the network robot project supported by the NICT is taking a leadership role. These efforts will make possible a new lifestyle with robots.

If robots working in our human society become reality, there is of course the possibility of our also using androids in our future life. The last figure portrays such a scene.

Acknowledgements

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