Development of androids for studying on human-robot interaction

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Abstract
Both the appearance and behavior of the robots are significant issues in the development of humanoids. 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 paper mainly introduces the developed androids as the test bed.

1. INTRODUCTION

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 phenomenon, 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.

1.1 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.

1.2 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 are 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.

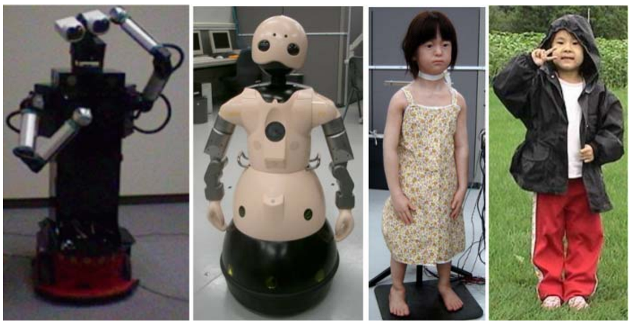

Figure 1: From humanoids to androids. The first robot (the left end) is Robovie II developed by ATR Intelligent Robotics and Communications Laboratories. The second is Wakamaru developed by Mitsubishi Heavy Industry Co. Ltd. The third is a child android, while the fourth is the master of the child android.

2. 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.

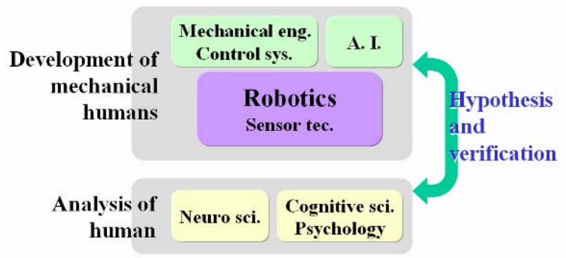

Figure 2: The framework of android science

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. More detailed information is available in the webpage **www.androidscience.com**.

3. DEVELOPMENT OF ANDROIDS

3.1 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 silicone full-body model is made from the plaster mold. This silicone model is maintained as a master model.

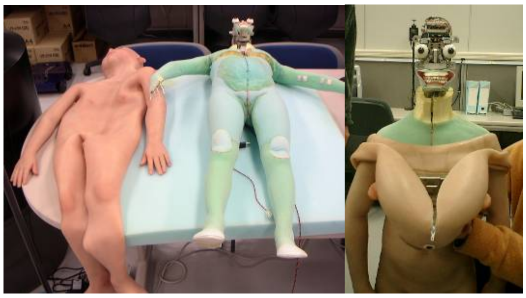

Figure 3: The silicone skin and inside mechanisms

Figure 4: Child android

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

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 silicone, more improvement is required in this area.

The current silicone 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.

3.2 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.

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.

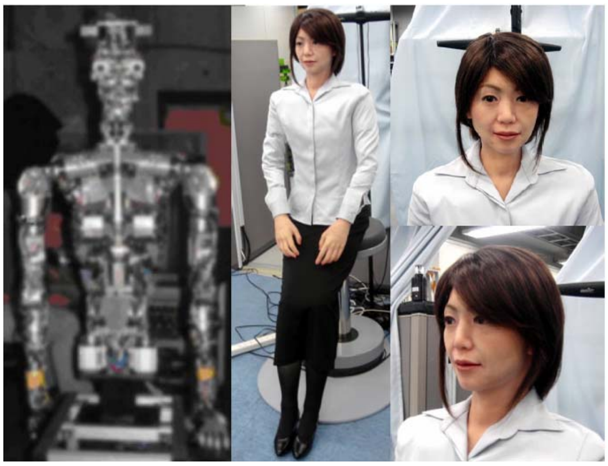

Figure 5: Adult android developed in cooperation with Kokoro Co. Ltd.

Figure 6: Facial expressions of the android

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.

3.3 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 (left) and android (right)

3.4 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.

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 silicone 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.

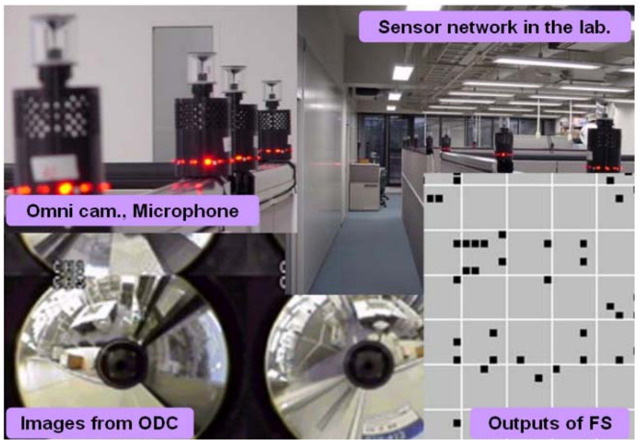

Figure 7: Distributed sensor system

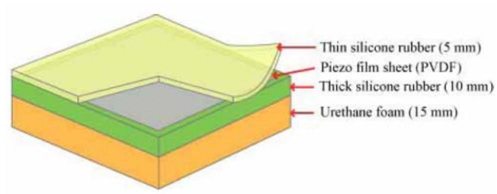

Figure 8: Skin sensor.

4. THE TOTAL SYSTEM

Figure 8 shows the total system that has been exhibited in the World Expo Aichi. The system shown in Figure 9 consists of the following parts including the android:

- 8 computers for analyzing the sensory data and controlling the android.
- The floor sensors covering the exhibition space.
- 8 omnidirectional cameras for recognizing large human gestures.
- 8 microphones for capturing the human voice.
- 2 pan-tile cameras for tracking human faces

Figure 10 shows the scene of the exhibit in the World Expo and Figure 11 shows a snap shot in an interaction with a visitor. The scenario for the interaction is as follows. When the visitor comes into the area of the exhibit, the android detects the position of the visitor and turns the head to the visitor and looks at the visitor. Then android behaves like a news reporter and ask questions, like "How was the World Expo?" The android recognizes simple answers of the visitor and takes reactions.

The exhibit was 10 days. During the period, the android kept working.

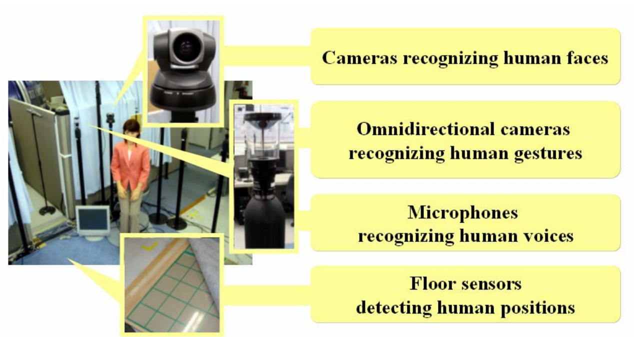

Figure 9: The total system

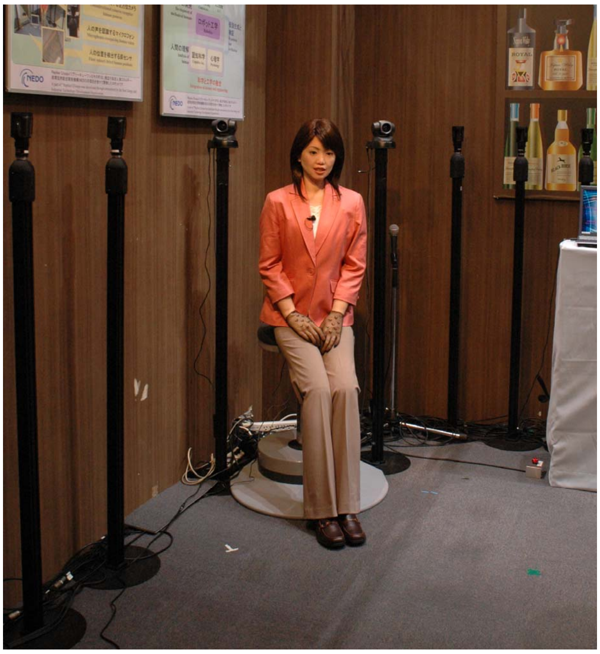

Figure 10: The exhibition of the android Repliee Q1expo

Figure 11: Interaction with a visitor

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