Evaluation of Android Using Unconscious Recognition

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***Abstract* - In human-robot interaction, both appearance and motion are essential aspects of the robot. We study human-robot interaction using an android that has human-like appearance.**

Mori [1] hypothesized the 'uncanny valley' which describes a relationship between appearance of a robot and the feeling it produces in humans. To design robots that interact successfully with humans, we must know the structure of the uncanny valley.

Humans show unconscious behaviors when interacting with another human. We expect the same behaviors when interacting with a very human-like robot. Then we can change appearance and motion to study how the unconscious behavior of the human changes. In this way, we explore the uncanny valley.

The unconscious behavior we consider in this study is gaze behavior. It has been found [2,3] that eye movements are used to send social signals during conversation. In particular, when thinking about the answer to a question, humans tend to look away from the questioner. We hypothesize that if the human-likeness of the questioner changes, this gaze behavior also changes. We compare three different questioners: human, android and robot with a 'mechanical' appearance.

We found that the subject changes gaze to the left of the face a longer time in case of a human or android questioner. The subject changes gaze to look down from the face in the case of a mechanical robot questioner. There is a significant difference between these two behaviors.

We conclude that the android questioner is unconsciously treated in the same way as the human questioner. The mechanical robot is treated differently from the human questioner. These results will become clues to the uncanny valley and contribute to the progress of human-robot communication.

Index Terms – Android, Appearance and behavior, Comparative Psychology, Gaze behavior, Interaction.

I. INTRODUCTION

Our everyday impressions of intelligence are subjective phenomena that arise from our interactions with others. The development of systems that support rich, multimodal interactions will be of enormous value. Our research goal is to discover the principles underlying natural communication among individuals and to establish a methodology for the development of expressive humanoid robots. The top-down design of robots is impossible because human models do not fulfill the necessary requirements. We adopt a constructivist approach that entails repeatedly developing and integrating behavioral models, implementing them in humanoid robots, analyzing their flaws, and then improving and reimplementing them [4].

By following this constructivist approach, we have developed a humanoid robot ``Robovie," which has numerous situation-dependent behavior modules and episode rules to govern the various combinations of these modules and rules [5]. This has enabled us to study how Robovie's behavior influences human-robot communication [6]. However, based on the fact that human beings have evolved specialized neural centers for the detection of bodies and faces (e.g., [7]), we can infer that a humanlike appearance is also important. Apart from gestures, human beings may also possess many biomechanical structures that support interaction, including scores of muscles for controlling facial expressions and the vocal tract. Robovie's machinelike appearance will have an impact on interaction, thereby preventing us from isolating the effects of behavior. Other studies have also tended to focus only on behavior, and have entrusted the robot's appearance to an artistic designer. However, in order to isolate the effects of behavior from those of appearance, it is necessary to develop an android robot that physically resembles a person. Our study addresses the appearance and behavior problem from the standpoint of both engineering and science. We also explore the essence of communication.

Studies on androids have two research aspects:

- *The development of a humanlike robot based on mechanical and electrical engineering, robotics, control theory, pattern recognition, and artificial intelligence.*
- *An analysis of human activity based on the cognitive and social sciences.*

These aspects interact closely with each other: in order to make the android humanlike, we must investigate human activity from the standpoint of the cognitive and behavioral sciences as well as the neurosciences, and in order to evaluate human activity, we need to implement processes that support it in the android.

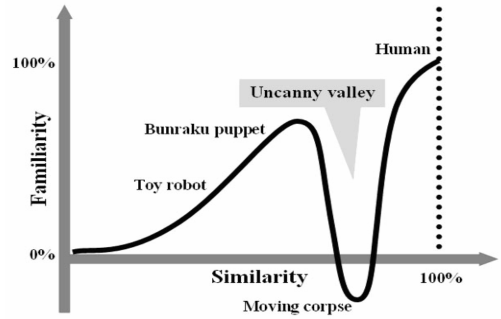


Fig.1 The uncanny valley [1, 8]

This paper proposes a direction for android research based on our hypothesis on the relationship between appearance and behavior. It also reports a study that evaluates the human likeness of an android based on human gaze behavior.

Gaze behavior in human-human interaction has been studied in psychology and cognitive science. For example, some psychological researchers studied functions of eye contact in human-human conversation [9] and a relationship between duration of eye contact and interpersonal relationship [10]. According to existing studies on human gaze behavior, we can infer that the gaze behavior is influenced by interpersonal relationship. Conversely, we can infer that the interpersonal relationship can be evaluated by observing the person's gaze behaviors. In this paper, gaze behaviors in human-android interaction are compared with those in human-human interaction and human-robot interaction in order to evaluate human likeness of an android.

Ⅱ. A RESEARCH MAP BASED ON THE APPEARANCE AND BEHABIOR HYPOTHESIS

A. A Hypothesis about a Robot's Appearance and Behavior

It may appear that the final goal of android development should be to realize a device whose appearance and behavior cannot be distinguished from those of a human being. However, since there will always be subcognitive tests that can be used to detect subtle differences between the internal architecture of a human being and that of an android [11, 12], an alternative goal could be to realize a device that is almost indistinguishable from human beings in everyday situations. In the process of pursuing this goal, our research also aims to investigate the principles underlying interpersonal communication.

A significant problem for android development is the ``uncanny valley," which was first suggested by Mori [1, 8]. He discussed the relationship between a robot's similarity to a human and a subject's perception of familiarity. A robot's familiarity increases with its similarity until a certain point is reached at which imperfections cause the robot to appear repulsive (Fig.1). This sudden drop is termed as the uncanny valley. A robot in the uncanny valley may seem like a corpse. We are concerned that these robots we create in our development of androids could also fall into the uncanny valley owing to imperfections in appearance. Therefore, it is necessary to adopt a methodology that will enable us to overcome the uncanny valley.

B. The Android Research Map

How do we quantify similarity and how do we evaluate human-robot interaction? In order to answer these questions, some main research issues need to be addressed.

A method to evaluate human-robot interaction

Human-robot interaction can be evaluated by its degree of ``naturalness." Therefore, it is necessary to compare human-human and human-robot interactions. There are qualitative approaches to measure a mental state using methods such as the semantic differential (SD) method. There also exist quantitative methods to observe an individual's largely unconscious behavior, such as gaze behavior, interpersonal distance, and vocal pitch. These observable responses reflect cognitive processes that we might not be able to infer from responses to a questionnaire. In this research, we study how a human subject's responses reflect the humanlike quality of an interaction and how these responses are related to the subject's mental state.

The development of humanlike robots


Fig.2 : The developed android Repliee R1

We have developed two androids that are currently being used for experimentation. Repliee R1, shown in Fig.2, is based on an actual five-year-old girl. We took a cast of her body to mold the android's skin, which is composed of a type of silicone that has a humanlike feel. The silicone skin covers the entire body of the android. To enable it to assume various postures, it has nine degrees of freedom in the head and many free joints. All actuators (electrical motors) are embedded within the body. The main limitations of this android are as follows:

- Repliee R1's range of motion is limited by the low elasticity of the silicone skin.
- The eye and eyelid mechanisms are not perfectly realized, which is a drawback because people are sensitive to imperfections in the eyes.

These limitations must be overcome in order to achieve a humanlike appearance.

Fig.3 : The developed androids Repliee Q1 and Repliee Q2. The details of the inside mechanism are blurred

Repliee Q1, shown in Fig.3(a), is our other android; this android was developed to realize humanlike motion. It has 31 degrees of freedom in the upper body. It can generate various kinds of micro-motions such as the shoulder movements that are typically caused by human breathing. Silicone skin covers only its head, neck, hands, and forearms thereby enabling a wide range of motions to be realized. The compliance of the air actuators makes for safer interactions. Highly sensitive tactile sensors mounted just under the android's skin enable contact interaction.

Repliee Q1 has now been upgraded to Repliee Q2 shown in Fig.3(b). It has 42 degrees of freedom and can make facial expressions and finger motions in addition to the movements that Repliee Q1 can make. It has 16 degrees of freedom in the head. The face was modeled after a particular Japanese woman in order to realize a more humanlike appearance. The facial expressions of the android enable various social interactions.

In the next section, we present a study to evaluate the human likeness of the android based on human gaze behavior during communication.

Ⅲ. EVALUATION OF THE HUMAN LIKENESS OF THE ANDROID

In order to make the android humanlike, we must evaluate the human likeness of the android. Therefore, as mentioned above, it is necessary to compare human-human with human-robot and human-android interactions. Apart from the android, Oztop et al. [13] adopted an experimental paradigm of motor interference to investigate how similar the implicit perception of a humanoid robot is to a human agent. They measured the amount of interference in a subject's movement when s/he performed an action which was incongruent to other's action, and evaluated the human likeness of the humanoid robot with the interference effect. In the evaluation of a human-robot interaction, methods of evaluating a human subject's responses provide a complementary source of information to the insights gleaned from a questionnaire or focus group. Therefore, the difference between human-human and human-android interactions can be evaluated by observing such person's responses as can be influenced by a social relationship to other individuals.

We studied the interaction between the android Repliee R1 and a person [14]. We focused on the subject's gaze fixation during a conversation. The pattern of fixation in the case of the android interlocutor was different from that of a human interlocutor. Many subjects perceived the android's appearance and movement to be artificial. Thus, we concluded that the unnaturalness of the android affected the subjects' gaze fixation.

In our previous work, we found that it was necessary to improve Repliee Q1 to have it judged human [15]. This paper evaluates the human likeness of the android Repliee Q2, which is an improved version of Repliee Q1. The evaluation method is the same as in previous work: gaze behaviors. In our previous experiments, we didn’t compare with a robot with a “mechanical” appearance. Therefore, we couldn’t evaluate how the human likeness of the android compares to that of a robot. In this experiment, we compare human, android, and robot.

In this study, we focus on a particular aspect of gaze behavior, which is evaluated through a set of experiments. On one hand, this helps to investigate the design methodology of humanoid robots; on the other hand, by studying the nature of gaze behavior, we can contribute to cognitive science and psychology.

A.. Breaking Eye Contact while Thinking

Gaze behaviors in human-human interaction have been studied in psychology and cognitive science, and the gaze behavior in human-android interaction can be compared to it. Some gaze behaviors are conscious and others are unconscious. This paper focuses on breaking eye contact while thinking, which is one of unconscious gaze behaviors.

The tendency to break eye contact during a conversation has been studied in psychology. While thinking, people sometimes break eye contact (avert their eyes from the interlocutor). There are three main theories that explain this behavior:

- **The arousal reduction theory**

There is a fact that arousal is the highest when a person makes eye contact during face-to-face communication [16]. This theory suggests that people break eye contact while thinking to reduce their arousal and concentrate on the problem [17].

- **The differential cortical activation hypothesis**

This hypothesis suggests that brain activation induced by thinking tasks leads individuals to shift their gaze away from the central visual field [18].

- **The social signal theory**

This theory suggests that gaze behavior acts as a social signal; people break eye contact to inform others that they are thinking.

If breaking eye contact were a kind of social signal, we would expect it to be influenced by the interlocutor. Psychological researchers have reported that there are experimental evidences to support the social signal theory [2, 3]. We report an experiment that compares subjects' breaking of eye contact with human, android, and mechanical robot interlocutors.

We hypothesize that if the manner in which eye contact is broken while thinking acts as a social signal, subjects will produce different eye movements if the interlocutor is not humanlike or if the subjects do not consider the interlocutor to be a responsive agent. Conversely, if eye movement does not change, it supports the contention that subjects are treating the android as if it were a person or at least a social agent.

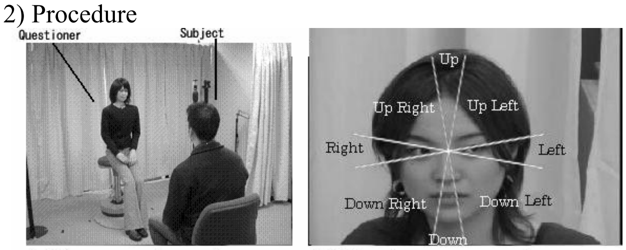
B. Experiment

1) ‘Mechanical’ robot used in experiment

Fig.4 robot Eveliee P1 used in the experiment

Eveliee P1, shown in Fig.4, is used in this experiment. Body size of robot is 100[cm] high, and 60[cm] wide. This robot has wheels, with which it moves forward, backward, and rotates. It has 11 degrees of freedom. Its appearance is “mechanical” and “metallic”. In this, it differs greatly from the android. In this experiment, the robot’s lower body doesn’t move, because the android’s also cannot.

2) Procedure



(a)The experimental setup (b)The discrete eye direction

Fig.5 The experimental scene and the eight averted gaze direction

The subjects were made to sit opposite a questioner (Fig.5(a)). The subjects' eye movements were measured while they were thinking about the answers to questions posed by the questioner. There were two types of questions: “know questions” and “think questions”. The know questions were used as a control condition. Know questions were those to which the subjects already knew the answers (e.g., ``How old are you?"). Think questions, on the other hand, were those questions to which the subjects did not already know the answers because the subject was compelled to derive the answer (e.g., ``Please tell me a word that consists of eight letters.").

The subjects were asked 10 know questions and 10 think questions in random order. Table 1 shows the questions. Their faces were videotaped and their gaze direction was coded from the end of the question to the beginning of the answer. The video records of each subject's eye movements were analyzed frame by frame. The average duration of gaze in the eight directions shown in Fig.5(b) was then calculated.

Table 1 know questions and think questions the questioner asked.

Think questions
・Do you know a flower whose name is also used as a first name given to women?
・If your mother’s brother or sister has a child, what is the relation between that child and you?
・Please name a fruit which is red on the inside.
・Please say the word “sikayama” backward.
・Six times three divided by two.
・Please tell me a word that consists of eight letters.
・What distance can a car travel in 1.5 hour, when its speed is 60 kilo meters an hour?
・Please enumerate all the months that have 30 days.
・Name a color that doesn’t appear in the rainbow ?
・How many occurrences of ‘n’ are in the word of “’ni’’ho’’n’’ka’’n’’jo’’u’’si’’n’’ri’’ga’’ku’’ka’’i’” ?
Know questions
・What is the name of this university?
・How many sides does a square have?
・When a traffic signal is red while driving a car, what should you do?
・What is the sweet substance called that bees make?
・What is “tofu” made from?
・How old are you?
・What year is it currently in the Gregorian calendar?
・Who is the prime minister of Japan?
・What is the name of animal that make the sound “moo”?
・What is the capital of Japan?

Three types of questioners were used: a Japanese person (human questioner), the android Repliee Q2 (android questioner), and Eveliee P1 (robot questioner). In order to make the android appear as humanlike as possible, we conducted the experiment of the case of the android questioner in the following manner: A speaker embedded in the android's chest produced a prerecorded voice. In order to make the android appear natural, it was programmed such that it displayed micro-behaviors such as eye and shoulder movements. At first, the experimenter seated beside the android explained the experiment to the subject in order to habituate the subject to the android. During the explanation, the android behaved like an autonomous agent (e.g., it continuously made slight movements.)

In the case of a ‘mechanical’ robot, subjects habituate to the robot in the same manner as described for the android. The robot was given micro-behaviors similar to those of the android. The motions were kept small enough to not distract the subject’s gaze.

The detailed experiment procedure is as follows. The experimenter explains to the subjects the alleged purpose of experiment saying: “the purpose of this experiment is to investigate how you answer a question, when you are asked in a face to face interview style. The questioner will ask several questions. Please answer the questions loud and clearly. Do you have any question on the procedure?” We make sure the subject does not have any question, and after that the experimenter exits the experimental environment to start the experiment.

The questioner addresses the subject with: "Hello, let's start now." Then the questioner asks a series of questions. After the last question, the questioner tells the subject: "that's all・ Thank you." Finally, the experimenter tells the subject that the experiment is finished.

The subjects in the case of the human questioner were 29 Japanese adults (15 men and 14 women). Their average age was 33.1 years. The subjects in the case of the android questioner were 28 Japanese adults (15 men and 13 women). Their average age was 30.2 years. The subjects in the case of the human questioner were 28 Japanese adults (15 men and 13 women). Their average age was 29.2 years. The subjects were recruited from a temporary employment agency. Most of them were unfamiliar with the android. Each subject was asked to read and sign a consent form before the experiment. In order to avoid that a subject was asked the same questions, each subject participated in only one case of questioner.

3) Result

The top rows of Table 2 and Table 3 show the average percentage of times that the subjects looked in each eye direction in the case of the human questioner; this has been illustrated by the polar plot in Fig.6. In the same manner, the middle rows of Table 2 and Table 3, and Fig.7, show the results in the case of the android questioner. The bottom rows of Table 2 and Table 3, and Fig.8, show the results in the case of the robot questioner.

In order to examine the effect of questioner on the duration of breaking eye contact, a repeated measures three-way ANOVA with one between subject factor (questioner) and two within subject factors (question type and eye direction) was conducted. There were significant effects of question type ($F(1,82)=277.26$, $p<10^{-27}$), eye direction ($F(7,574)=9.17$, $p<10^{-8}$),and interaction between questioner and eye direction ($F(14,574)=2.63$, $p<.01$). No main effect of questioner was found. That is why average percent duration of looking away from the questioner did not change between questioners. For investigating interaction between questioners and eye directions, Tukey's HSD test was conducted. As a result, we found significant differences between looking down in case of the robot and either human or android, and between looking to the left in case of the robot and either human or android.

From Fig.6, Fig.7, and Fig.8 it can be seen that subjects tend to avert their eyes to the left and to the right in case of an android questioner and a human questioner, when the questioner asks a "think" question. Subjects tend to avert their eyes down in case of a robot questioner, when the robot asks a "think" question. To investigate similarity of graph shapes, we calculated inner product between human and android, and human and robot. Elements of the vector were average percentage of duration of gaze in each averted direction. The value of the inner product in case of the android is 0.95, and that in case of the robot is 0.87. Therefore, we conclude that gaze behavior in case of the android, rather than that in case of the robot, is similar to the human case.

C. Summary

In this experiment, the subjects showed unconscious interpersonal reactions in case of the android Repliee Q2, similar to those shown in the case of android Repliee Q1 in previous work [15]. These unconscious reactions were also shown in interaction with the robot. However, the gaze pattern in the case of the android questioner was very similar to that in the case of the human questioner, and different from that in the case of the robot questioner. That is to say, subjects treated the android as if it were a person in this situation. Further, this gaze pattern emerges only in interaction with the android.

In this experiment, we evaluated the android comprehensively. However, it is not clear how individual aspects of appearance and motion of the android influence human unconscious reaction and furthermore, which aspects are most influential.

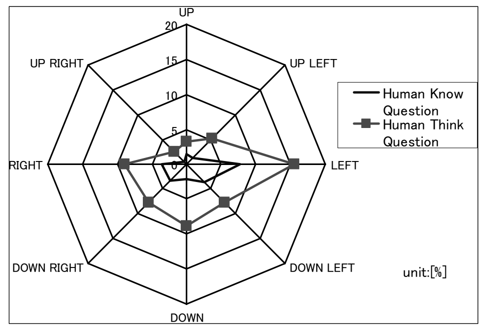


Fig.6 Average percentage of duration of gaze in eight averted directions for a human questioner

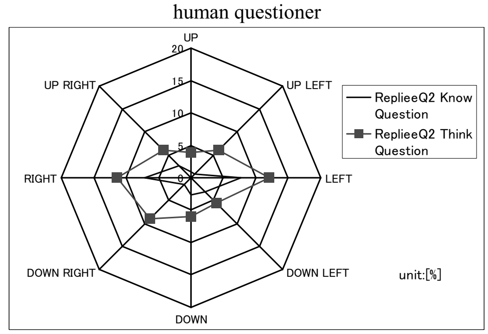


Fig.7 Average percentage of duration of gaze in eight averted directions for an android questioner

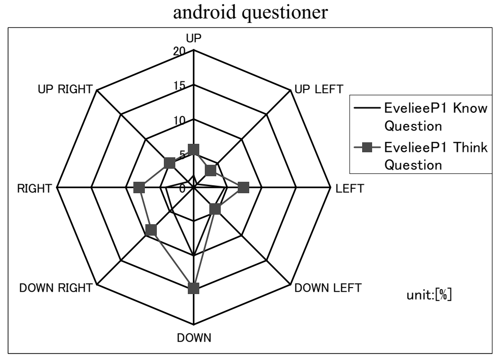


Fig.8 Average percentage of duration of gaze in eight averted directions for a robot questioner

Table 2 Mean and standard deviation of gaze duration in each direction of know question

Know question Unit:[%]		UP	UP LEFT	LEFT	DOWN LEFT	DOWN	DOWN RIGHT	RIGHT	UP RIGHT	Eye Contact
Human	ave.	1.50	1.33	7.73	3.62	2.12	3.31	3.60	0.50	76.29
	std.	4.54	2.85	10.42	6.11	4.91	6.48	5.86	1.62	15.20
ReplieeQ2	ave.	0.86	0.77	7.70	3.08	2.65	1.46	7.07	2.70	73.71
	std.	2.01	2.25	10.40	8.75	5.34	4.03	10.86	5.57	20.31
EvelieeP1	ave.	1.72	0.56	4.59	4.12	10.05	4.50	4.09	1.12	68.65
	std.	3.53	2.02	7.06	7.64	9.20	8.31	5.75	2.85	19.96

Table 3 Mean and standard deviation of gaze duration in each direction of think question

Think question Unit:{%}		UP	UP LEFT	LEFT	DOWN LEFT	DOWN	DOWN RIGHT	RIGHT	UP RIGHT	Eye Contact
Human	ave.	3.28	5.14	15.57	7.79	8.85	7.78	8.95	2.42	40.09
	std.	11.10	7.41	14.97	9.74	12.82	14.05	9.81	5.52	20.56
ReplieeQ2	ave.	3.92	6.05	12.05	5.47	5.98	8.95	11.36	6.07	40.05
	std.	5.64	9.23	11.23	9.00	6.13	14.22	14.23	6.70	19.30
EvelieeP1	ave.	5.49	3.37	7.23	4.44	14.71	8.72	7.90	4.94	42.52
	std.	8.81	5.52	9.76	4.95	9.80	11.48	10.24	5.45	19.63

Ⅳ. CONCLUSION

This paper proposed a hypothesis about how appearance and behavior are related and mapped out a plan for android research in order to investigate the hypothesis. The action of breaking eye contact while thinking was considered from the standpoint of the appearance and behavior problem. In this study, we used the android to investigate the sociality of gaze behavior while thinking. We obtained evidence that the gaze pattern in interaction with the android and a human is the same, and different from the gaze pattern towards the robot. These results suggest that unconscious reactions are useful in investigating the human likeness of the android. These results will become clues to the structure of the uncanny valley. By gradually changing the appearance or motion of the android, and studying human reactions, we believe the structure of the uncanny valley will become clear. However, a more comprehensive study is required to explain the results in order to contribute to human psychology.

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