

Android as a Telecommunication Medium with a Human-like Presence

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ABSTRACT

In this research, we realize human telepresence by developing a remote-controlled android system called Geminoid HI-1. Experimental results confirm that participants felt stronger presence of the operator when he talked through the android than when he appeared on a video monitor in a video conference system. In addition, participants talked with the robot naturally and evaluated its human likeness as equal to a man on a video monitor. At this paper's conclusion, we will discuss a remote-control system for telepresence that uses a human-like android robot as a new telecommunication medium.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces-Interaction styles, I.2.9 [Artificial Intelligence]: Robotics

General Terms

Design, Experimentation, Human Factors, Verification.

Keywords

Android Science, Humanoid Robot, Telepresence, Telecommunication.

1. INTRODUCTION

Recently, many humanoid robots have been developed. For instance, Honda developed ASIMO, a famous humanoid robot that can walk on its biped legs. Breazeal et al. developed a face robot that can express facial emotions for interacting with people [1]. Moreover, a very human-like robot, or an android, has been developed [2]. Such human-like body properties of robots will be used for natural human-robot interaction [3-6].

We believe that a humanoid robot, particularly an android robot,

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can also be used as a telecommunication medium for distant inter-human communication. Previous media, such as video conference systems, have problems with effective presence; since people don't feel they are sharing physical space [7], it is hard to identify eye-gaze [8] and so forth.

In telepresence research, virtual reality techniques are often used; however, the advantages of robots as computer-graphic agents have been demonstrated. Kidd and Breazeal compared a robot and a computer-graphic agent and found that the robot was more suitable for communication about real-world objects [9]. Shinozawa et al. also argue that a robot is more appropriate for communication referring to real objects than a computer-graphic agent [10]. Since we are interested in presence in the real world, we focus on an approach based on real robots.

Several telepresence research works are based on real robots. For instance, Sekiguchi et al. developed a telephone system where two stuffed-animal-type robots were placed at both ends and synchronized in motion so that people could exchange feelings of movement [11]. Tadakuma et al. used a humanoid robot whose operator was projected on its face [12]. However, conveyed human presence is not yet as real as actual humans.

In this study, we utilize an android presence that resembles a human for distant inter-human communication. This paper reports an experiment to reveal how an android can convey human presence compared with a speakerphone and a video.

2. Android Telecommunication System

We developed a remote-controlled android system that uses a very human-like robot called Geminoid HI-1 (a copy of co-author Hiroshi Ishiguro).

Since we focus on the realization of telepresence and communication using a telecommunication system, our initial system was developed as a teleoperation system. Such previous media as telephones and video conference systems were easy for users, telepresence and communication operations must also be easy. To achieve this, we will develop the android as a semi-automatic controlled system.

In this section, we introduce Geminoid HI-1 and the telecommunication system.



Figure 1: Actual living man (left) and his copy named Geminoid HI-1

2.1 Geminoid HI-1

Since Geminoid HI-1, a copy of a man, was developed to resemble a human as much as possible, its appearance is actually human-like. This android is 140 cm tall sitting in a chair (it cannot stand) and has 50 DOF. Its face has 13 DOF, which gives it natural facial expressions.

Figure 1 shows the Geminoid HI-1 and its real human counterpart.

Natural and Human-Like Motions

A very human-like appearance involves natural and human-like motion development. If we ignore this, then its impression will immediately be bad. We are trying to employ this robot as a telecommunication medium, so we must avoid such negative impressions to realize natural telecommunication.

When we prepared its motions to be natural, we tried to make its motions as similar as the original man's motions. Of course, the definition of "naturalness" is vague; however, since the android's appearance is very similar to the original man, we believe that this criteria work well.

The system continuously plays motion files in order to control this android's body movements. Motion builders who are engineers of developing robot's motions define the motion files. Third person evaluate developed motions to help motion builders improve the naturalness of the motions.

2.2 Behavior Controller

There are two levels of difficulties in realizing android's natural behavior in teleoperation: conscious and unconscious. For the conscious level problem, the difficulty comes from the burden of excessive operations to control everything about the robot. Geminoid HI-1 has 50 actuators. It is hard for operators to control all actuators directly. For that reason, we simplified remote

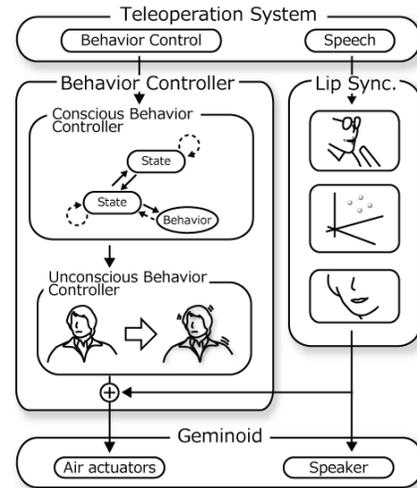


Figure 2: System Overview

control by choosing a semi-automatic system to solve this problem. A teleoperator simply switches the robot's behaviors.

Regarding unconscious level difficulties, the problem is subtle expression, which we solved by realizing unconscious behavior control. A human-like robot such as Geminoid HI-1 can express delicate motions. On the other hand, if we do not design its motions expressively, humans will not react favorably to its appearance. This will obstruct the achievement of telepresence. The unconscious behavior controller automatically generates or embeds the robot's unconscious behaviors to realize natural motion that includes trepidation. A system overview is shown in Figure 2.

We present the details of the semi-automatic and remote-control systems below.

2.2.1 Conscious Behavior Controller

This system has an internal "state" with which it can be automatically controlled. The state continues to randomly play individual motion files that define robot motion and realize automatic control. The present system has 20 unique motion files for each state. In addition, this system can play an individual motion file that is not in any state. In this case, a state returns to the last state when it has finished playing a file. The teleoperator controls this system that switches the states and plays individual behaviors.

States

We define five states in this system from which the teleoperator can select to match the situation:

1. Idle:
 - The robot stares straight ahead, but slightly bends his head. He sometimes looks to the left or right.
2. Speaking:
 - He stares straight ahead and sometime looks to the left or right. This behavior resembles a more active idle state.
3. Listening:

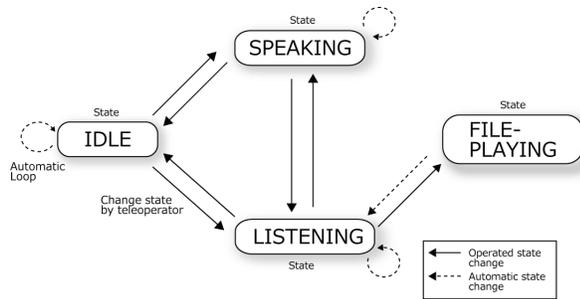


Figure 3: Example of State and Behavior Control

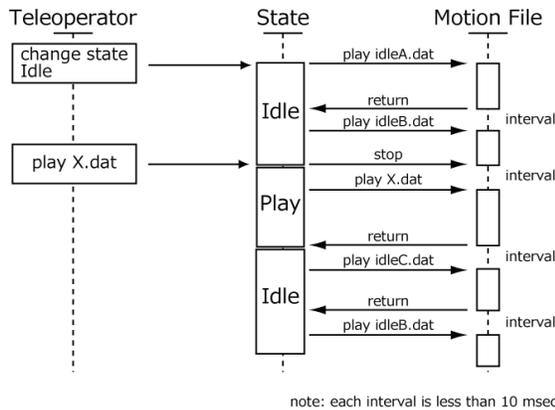


Figure 4: Behavior Control Sequence

This state is less active than the speaking state to project an image of listening.

4. Left-looking: This state looks to the left to make eye contact in that direction and resembles the speaking state.
5. Right-looking: This state looks to the right to make eye contact in that direction and resembles the speaking state.

State Transition Example

Here we briefly show an example of state transition. Figure 3 shows three states and one FILE-PLAYING state. FILE-PLAYING state is prepared for making the android speak particular sentences, such as greeting. When a command for a state transition comes from the teleoperator, the conscious behavior controller moves the state to the next that specified by the teleoperator. When a command for a move to FILE-PLAYING state with motion filename comes, the conscious behavior controller plays the motion file which specified by the teleoperator. And when the motion has finished playing, the controller returns to the previous state.

Figure 4 shows the details of this flow. You can see the sequence of state transition and treatment of the motion files.

2.2.2 Unconscious Behavior Controller

Humans perform such unconscious behaviors as breathing, blinking, and trembling. However, we do not notice most of them. Only when they are missing do we feel that something is wrong.



Figure 5: Our remote-control system



Figure 6: View of Remote Operation System

Thus, unconscious behaviors must be expressed by androids for telepresence applications.

Our system treats this problem as unconscious behavior control. It adds subtle expressed motions to the original motions selected by a conscious behavior controller. In particular, when this system plays a motion file, the unconscious behavior controller adds breathing behavior to the original one. Currently, this controller has not so many functions. However, we will improve it to realize human-like motion on Geminoid HI-1.

2.3 Teleoperation system

A teleoperator remotely controls the android's behaviors by choosing its state. We also prepared a function which synchronizes the lip motions between the teleoperator and the android. In this system we employ Geminoid HI-1 as a telecommunication medium. It is important that the voice transfer with mouth movement. If speech and lip movements are not matched, people will not have good impressions due to Geminoid HI-1's very human-like mouth. Therefore we control its mouth to be equal to the teleoperator's mouth movements, which is measured by a motion capturing system.

Figure 5 illustrates our remote-controlled system. Two monitors display the room condition, and one desktop computer is used by the teleoperator for remote control. In addition, we have five optical cameras for motion capturing. In this way the teleoperator remotely controls Geminoid HI-1 (Figure 6).



Figure 7: Geminoid Controller Interface

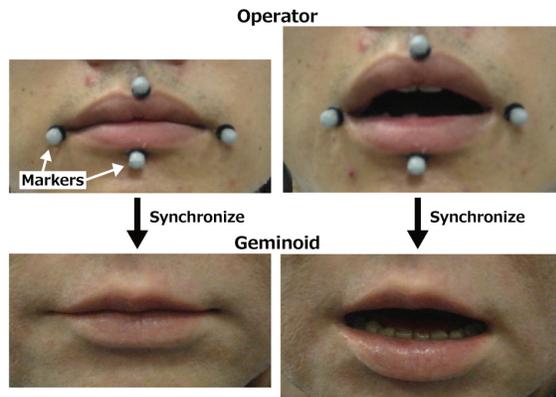


Figure 8: Operator Lip Synchronization with Geminoid HI-1

We explain this remote-control system in detail below.

2.3.1 Behavior Control

We developed a remote control protocol to switch states and play individual motion files. In particular, we implemented a command system to quickly sort through the states and play motion files.

We briefly show the remote control commands.

Change state <State name>

This command is for the state transition.

Get state

This command returns the current state of the robot.

Play motion <Filename>

This command plays an individual motion file.

Stop motion

This command stops the current motion file.

Operators easily realize complex robot behavior by combining these commands on an interface (Figure 7).

2.3.2 Speech and Lip Synchronization

The remote-control system is not only controlled by commands. Since motion files are prepared in advance, it is impossible to synchronize lip motion between a teleoperator and a robot only using motion files. So we decided to use a motion capturing system to synchronize lip movements and speech output from the robot's speaker. A motion capturing system, used to measure teleoperator's lip movements, has five pairs of infrared cameras



Figure 9: Eye Contact with Geminoid HI-1 and Teleoperator

and markers that reflect infrared signals. These cameras were set around the desk. As shown in Figure 8, we attached four markers around the teleoperator's mouth. Android expresses the lip movements as same as teleoperator's which measured by the motion capturing system.

3. Experiment

3.1 Outline

The purpose of our experiment is to verify the usefulness of an android as a telecommunication medium. Our hypothesis argues that in a sophisticated android robot we can realize a human-like presence that represents a remote person's presence. Thus, we are particularly interested in measuring presence, human likeness, and naturalness. Presence is expected to be the android's strong "suit" as a telecommunication medium due to its physical existence. Moreover, we believe that it can preserve the human likeness and naturalness of such communication media as telephones and teleconference systems.

In the experiment, an operator participated in a three-person conversation with the android. For comparison, they also conversed by video conference system and speakerphone. During the conversation session, the two participants mainly talked in the presence of the operator after he initiated the discussion. After the conversation, participants evaluated the medium.

3.2 Method

3.2.1 Participants

Thirty four university students were recruited and paired to participate in an experiment that featured a within-subject design, which means that each paired participant took part in three sessions for all conditions. The experiment was performed with a counterbalanced design. Participants were assigned completely at random.

3.2.2 Conditions

There were three conditions:

G condition

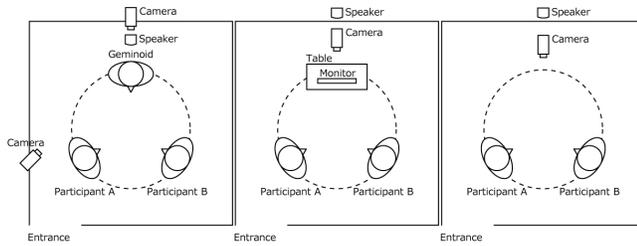


Figure 10: Experimental room setting
(left: G condition, center: V condition, right: S condition)

The operator talked with participants through Geminoid HI-1 and controlled its motion to express nodding and looking behaviors (Figure 9, top).

V condition

The operator talked with participants through a video conference system. Similar to the G condition, the operator only nodded and looked at the participants on his left and right without performing such behaviors as smiling, moving his hands, shaking his head, and so forth. Looking direction was calibrated in advance so that participants could feel that the person was looking at them (Figure 9, bottom).

S condition

The operator talked with participants through a speakerphone.

3.2.3 Environment

The experiment was conducted in a 3 x 3 m room. Figure 10 shows the setting of the experimental environments. The figure on the left shows the setting for the G condition. Chairs for participants and the Geminoid HI-1 were placed in a 1 m circle. In the V condition, we placed a monitor at the same height as Geminoid HI-1's head where the operator's face was displayed (Figure 10, center) at a similar size as the G condition. In the S condition, there were no extra equipment was included without the cameras and chairs. In all conditions, cameras were set up to allow the operator to look at the participants. In the V and S condition, a speaker was placed on the back of wall. In the G condition, a speaker was placed on the back of Geminoid HI-1. In all conditions, the participants could not see the speakers. We coordinated the speaker volume to be equal among conditions.

3.2.4 Procedure

The following was the procedure of the experiment sessions:

1. An experimenter informed the paired participants that they must discuss a theme given remotely by a person who will participate in the conversation using some "equipment."
2. They were led into the experimental room where one of the three conditions was prepared (Figure 10).
3. After sitting down, the operator (not the experimenter) gave them the discussion theme, which they began to discuss.
4. One minute later and after the speaking participants had given their opinions, the operator gave them an additional discussion theme. This gave the operator an equal quality and quantity speaking chance in every experiment. Participants had difficulty continuing the discussion longer

than a minute because Japanese students are not used to discussing.

5. After two minutes elapsed, a second theme was given, as in step 4.
6. When three minutes had elapsed and the speaking participants had again given their opinions, the operator concluded the experiment and led the participants out of the experimental room.
7. Participants answered questionnaires.

Participants repeated this procedure three times for all conditions. We prepared three different themes (and six different additional themes) so that participants did not experience the same discussion theme twice. The discussion themes were counterbalanced within conditions.

3.2.5 Operators for experiments

Two operators alternatively appeared who were not the Geminoid HI-1 model. Regarding utterances, the operator only gave the discussion theme to initiate conversation and responded to questions, but did not intrude into discussions and avoided any vocal backchannel to control the experiment. We did not use a participant as the operator because we intended to control three conditions similarly.

3.3 Evaluation

After each session, participants answered a questionnaire that rated their impression of having a conversation with the third person on a 1 to 7 scale, where 7 is the most positive. The items are listed as follows:

Presence

Degree to which the participant felt the third person presented at the conversation.

Humanlike

Human likeness of the third person's appearance, movements, and behavior.

Naturalness

Naturalness of the third person's appearance, movements, and behavior.

Uncanny

Uncanniness of the third person's appearance, movements, and behavior.

Responsiveness

Degree to which the third person responded to the participants' behavior and conversation.

Eye contact

Degree to which the third person's eye contact met the participants'.

3.4 Hypothesis and expectations

The following are our hypotheses for the experiment:

Hypothesis 1:

With Geminoid HI-1, the operator conveys the strongest presence among these three media.

Hypothesis 2:

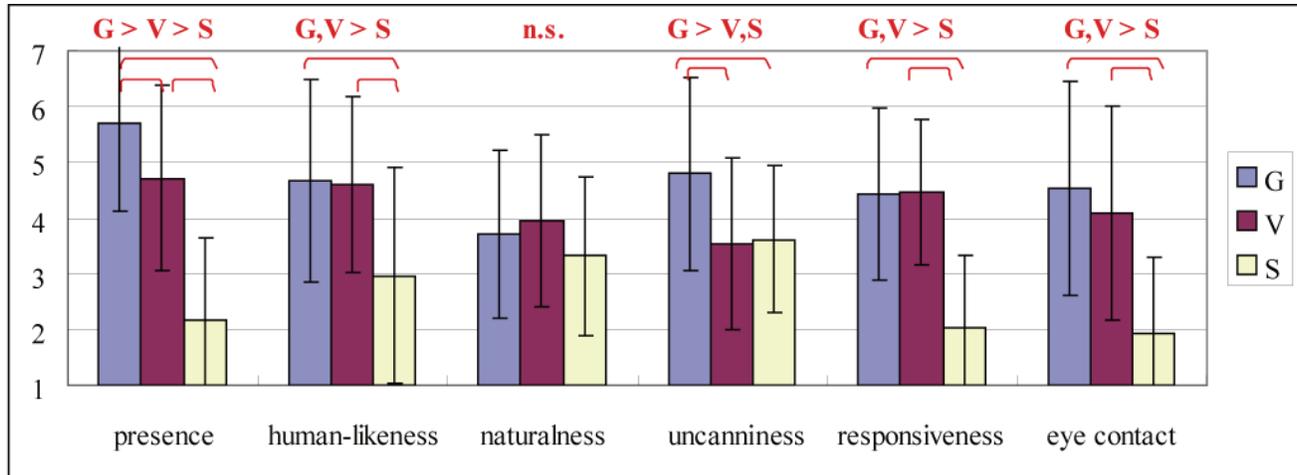


Figure 11: Participant impressions of three media: Geminoid android (G condition), video conference system (V condition), and speakerphone (S condition)

With Geminoid HI-1, the operator is perceived as humanlike and as natural as the other media.

Other measures:

We also measured uncanniness, responsiveness, and eye contact. Androids are generally considered uncanny, as explained by the Uncanny Valley theory [13]. Thus, we were interested in whether the android is deemed uncanny even when controlled by a human operator.

Since previous papers reported that one weakness of video conference systems is their eye contact capability [8], we investigated this strength of the android.

4. Results

Figure 11 indicates the means and standard deviations of the questionnaire results. We conducted a within-subject design analysis of variance (ANOVA) to investigate differences among conditions. The brackets above the boxes in Figure 11 show the significant differences of multiple comparisons at a 5% level of significance.

4.1 Hypothesis 1: Presence

A within-subject design ANOVA was conducted that showed significant differences in presence ($F(1,33)=50.762$, $p<.001$). A Bonferroni method was applied for multiple comparisons that proved that the rating of the G condition was significantly larger than the V and S conditions and that the V condition was significantly larger than the S condition ($G > V$, $p<.001$; $G > S$, $p<.001$; $V > S$, $p<.05$). This result indicates that as a medium, the operator conveyed the strongest presence with Geminoid HI-1.

4.2 Hypothesis 2: Human-like and Natural

A within-subject design ANOVA was conducted that showed significant differences in human-like ($F(1,33)=10.353$, $p<.001$). A Bonferroni method revealed that the G condition was significantly larger than the S condition and that the V condition was also significantly larger than the S condition ($G > S$, $p<.001$; $V > S$, $p=.001$). There were no significant differences in naturalness

($F(1,33)=1.777$, $p=.177$). These results indicate that in the G condition the operator gave similar human-like and natural impressions to the V condition.

In the S condition, the operator was deemed less human-like, although the same operator talked with the participants using the same quality of voice.

4.3 Analysis of other ratings

We also conducted a within-subject design ANOVA for the ratings of uncanniness, responsiveness, and eye contact that revealed significant differences among conditions ($F(1,33)=10.1$, $p<.001$; $F(1,33)=35.947$, $p<.001$; $F(1,33)=20.143$, $p<.001$). A Bonferroni method was applied for multiple comparisons. The G condition was significantly larger than the V and S conditions ($G > V$, $p=.001$, $G > S$, $p<.001$). Thus, the android condition was evaluated as more uncanny than the video conference and speakerphone conditions.

Regarding responsiveness, G and V conditions were significantly larger than the S condition ($G > S$, $p<.001$; $V > S$, $p<.001$). The same trend was found in the eye contact rating ($G > S$, $p<.001$; $V > S$, $p<.001$), perhaps reflecting the calibration performed for the operators. In the V condition, the operator looked in the left and right directions to make eye contact. For this reason, we performed calibration for the operator that affected the eye contact rating.

4.4 Summary of results

The results indicated that when the operator talked with participants through the Geminoid HI-1, they felt the strongest presence, similar level of human likeness and naturalness to a video conference system. Thus, we confirmed that the Geminoid android is a good telecommunication medium that can convey human-like presence by remotely representing human presence.

In the questionnaire, we asked about impressions of the operator. Since there were differences in the ratings among conditions even though the same operator appeared for the three conditions,

participants actually evaluated the effect of the medium rather than the operator.

Despite being evaluated as human-like and natural, the android was also described as uncanny.

5. DISCUSSIONS AND CONCLUSION

5.1 Summary

In this paper, we developed a remote-controlled android system that uses a very human-like robot called Geminoid HI-1. This system was developed to realize the telepresence of a teleoperator. To verify the presence of this system, we conducted an experiment whose results confirmed that this presence through this system is stronger than a man who only appears on a video monitor. In addition, the human likeness of Geminoid HI-1 equals a man's image on a video monitor. However, participants felt Geminoid HI-1 to be uncanny. Based on its strong presence and these results, a human-like robot can be a new telecommunication medium.

However, before using androids for telecommunication system, one important problem must be solved: uncanniness. Since the android gave a greater uncanny impression than the other media and even though it was rated human-like and as natural as a video conference system, its presence unfortunately increases feelings of uncanniness. Thus, more care is needed in the creation of androids to produce stronger presence.

5.2 Contributions for HRI

One major contribution of this research is that it demonstrated a novel way of human-robot interaction: a "teleoperated communication robot" [14] in which an operator behind the robot interacts with people in front of the robot, particularly with spoken language, while the system autonomously controls such low-level robot behaviors as breathing and lip movements.

Moreover, we believe that studying such a teleoperated communication robot will bring us more knowledge for developing completely autonomous communication robots that currently lack verbal communication capability. The principal difficulty concerns speech recognition of colloquial utterances in noisy environments. Current technology is only capable of recognizing formal utterances in noiseless environments. Although research is being done in robot audition, the difficulties in daily environments are still beyond the grasp of current technology. When a robust speech recognition technique becomes available, the knowledge of teleoperated communication must be integrated to realize ideal communication robots.

5.3 Contributions to android science

We believe that this research also contributes to android science [15], which aims to reveal what is human by developing a human-like robot that has human-like appearance and behavior. Our developed system will be a good platform for such study. For now, the android was evaluated as highly human-like but uncanny, and the person in the video was evaluated as similarly human-like but not uncanny. This might contradict the uncanny valley theory [13]. We believe that higher presence requires more human likeness to avoid the uncanny valley. In addition, note that although the participants were told that the android was controlled by a human

and were asked to rate the third person, they evaluated it as uncanny.

5.4 Applicability

Androids are still very expensive. One may be concerned with their applicability for telecommunication techniques. We suggest that in the future such important people in industry and government as presidents, politicians, and directors will use androids for telecommunication because they can afford them. For such people, "time is money," and sometimes physically meeting with people is more expensive in terms of time than money.

At the same time, in part, the obtained techniques for controlling the android can also be applied to teleoperated communication robots.

5.5 Limitations

The generality of the findings is limited because this research only dealt with a particular robot, Geminoid-HI-1, and two operators who were not the android model. The particular task only involved two people talking in the presence of the robot.

Regarding the generality of robots, the findings are limited to android robots, and the effect depends on android quality. If an android has equal or better human likeness, we believe that the findings will be applicable to the android.

Regarding the generality of the operator, the same effect probably happens when the operator is the model for the android; but, for people familiar with the modeled person, excessive similarity in appearance may cause a feeling of dissimilarity in motion and behavior. If the operator is very different, for example, a woman who speaks in a shrill voice, perhaps the interacting person will feel less human likeness due to the inconsistency between motion and speech.

As for the generality of tasks, the effects may change in relation to interaction complexity with the android. Since this study's purpose was to verify the fundamental effects of human-like presence, we focused on the role of the chairperson rather than those who actively joined the discussion. More complex interaction will require more sophisticated mechanisms, such as precise gaze direction control. In future work, we will investigate the human-like presence of androids in more complex interactions.

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