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GEMINOID: REMOTE-CONTROLLED ANDROID SYSTEM FOR STUDYING HUMAN PRESENCE

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Abstract: A large number of artifacts are called robots even if the developers did not intend to use that name for their products. However, we cannot say what is a “robot” clearly; there is a contradiction between the image of a “robot” and the actual existing robots. In this article, we first categorize robots into two categories. And then we describe that we focus on communication robots, especially, android robots. Following, we propose a remote-controlled android system called Geminoid HI-1. At this article’s conclusion, we will discuss a remote-control system that uses a human-like android robot as a new telecommunication medium and our sight of future robots.

Keywords: *Android, Humanoid, Robot, tele-communication, tele-presence*

1. INTRODUCTION

The growth of robotics has contributed to the development of various types of robots. However, there is a contradiction between the image of a “robot” and the actual developed robots. Therefore, it is difficult to clearly say what a “robot” is.

In this article, we first categorize robots into two groups. Then, we describe why we developed android robots. After that we propose our remote controlled android robot system, which is called Geminoid HI-1. We have conducted an experiment to evaluate how human-like this robot is. From these results, we will discuss the problems that our android has, and talk about future robots.

2. TWO CATEGORIES OF ROBOTS

When Karel Čapek created the concept of the “robot” as a work force in his book “R.U.R”, people started calling various artifacts “robots”. In particular, they called machines that acted autonomously robots. At this point, countless objects are called robots even if the developers did not intend to use that name for their products. Each of these robots is developed with an independent aim, such as to interact with humans, to do the same monotonous action over and over, to embark on a great adventure in space, and so on.

To understand this situation, we categorize robots as an automatic or semi-automatic machine and a communicable social entity in this article. This is examined in detail in the following section.

2.1 The robot as a (semi-) automatic machine

Millions of robots are already used as a work force. This includes not only industrial robots for factories, but also domestic robots such as dishwashers, clothes washers, and vacuum cleaners, and so on. Many robots work in extreme situations, like in deep-sea locations, outer space, and disaster stricken areas where humans are not able to enter or do work. Furthermore, army robots have also been developed and serve on the battlefield. On the other hand, a lot of people hope that robots will perform as care workers in hospitals and homes for the approaching “silver society.”

There are many robots that work not only autonomously but also semi-autonomously or fully controlled. Even if people control airplanes and cars, the machines can also decide their own actions because of their semi-autonomy. From that point of view, we can think of them as robots.

These robots are task-oriented robots and are not necessary to communicate with humans. This means that these robots are alternative work force to support human lives. Robots, in this sense, are already embedded our lives.

2.2 The robot as a social entity

While many robots are being developed as an alternative work force, there are also robots that are being developed to communicate with humans. These are communication robots. In the robots that are described in the previous section, the developers have no need to create a function that allows the robot to communicate with people or to provide their robots with an agent function. However, robots that are developed to communicate with people must have a human-like appearance and behaviors. In that sense, we believe that robots that serve as an alter-

native work force do not need a human-like appearance or animal-like behavior. However, communication robots require these traits. These robots also need to perform human-like communication. This means that these robots must be a social entity for people, because most of us are not going to communicate with an artifact like a stone. Robots that are communicative entities must have a human-like appearance or animal-like behavior to be recognized by people as a social entity.

Recently, many humanoid robots have been developed. For instance, Honda developed ASIMO, the 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]. A very human-like robot, called an android, has also been developed [2]. The human-like physical properties of such robots will be used for natural human-robot interaction [3-6].

We believe it is desirable for a robot that communicates and interacts with human to have a human-like appearance. That is to say, in the case of a person who is injured and receives care from a nurse in a hospital, he/she will want the care of a human or human-like robot. No one wants to receive the care of an industrial robot like a product being repaired in a factory.

To achieve those communication robots, it is important to verify the essentials of the objects as a communicable entity.

2.3 Robots we are considering

We are interested in communication robots that interact with people. In particular, we are interested in verifying the communication effects between humans and an android with a realistic human-like appearance.

A robot is a machine. That means it is an object. The robot may be an automatic machine or it may be a communicative entity that is simply a computer with arms, legs and a head. Even then, human kansei can feel anthropomorphism and zoomorphism from the artifact. In this research, we focus on this human ability. At this point, we aim to clarify and understand what is human, and exactly where human-likeness appears. Furthermore, to verify the communication effect of robots, we are interested in finding the borders between humans and robots.

To do that, we employ an android robot as a medium of tele-communication. First, we develop a semi-automatic android robot control system, and then we perform an experiment to verify how close the human-likeness of this system is to that of a human. We examine the developed system in detail and conduct an experiment in the following section.

3. ANDROID TELECOMMUNICATION SYSTEM

We believe that a humanoid robot, particularly an android robot, 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-gazing [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, the conveyed human presence is not yet as real as actual humans.

Therefore, 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) that has been developed by ATR Intelligent Robotics and Communications Laboratories.

Since we focus on achieving telepresence and communication using a telecommunication system, our initial system was developed as a teleoperation system. Just as previous media such 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.

3.1 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.

Figures 1 and 2 show the Geminoid HI-1 and its real human counterpart.

Natural and Human-like Motions

A very human-like appearance involves natural and

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

Figure 2: Geminoid and actual man (close)

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 achieve natural telecommunication.

When we prepared its motions to be natural, we tried to make them as similar as possible to 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 criterion works well.

The system continuously plays motion files in order to control the android's body movements. Motion builders, who are engineers for developing the robot's motions, define the motion files. A third person then evaluates the developed motions to help the motion builders improve their naturalness.

3.2 Behavior Controller

There are two levels of difficulty in achieving natural behavior for an android in teleoperation: a conscious level

and an unconscious level. 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 the remote control by choosing a semi-automatic system to solve this problem. A teleoperator simply switches the robot's behaviors. To do that, this system has an internal "state" with which it can be automatically controlled. The state continues to randomly play individual motion files that define the robot's motion and achieve automatic control.

Regarding the unconscious level difficulties, the problem is subtle expression, which we solved by achieving 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 hinder the achievement of telepresence. The unconscious behavior controller automatically generates or embeds the robot's unconscious behaviors to achieve natural motion, including trepidation. A system overview is shown in Figure 3.

3.3 Teleoperation System

A teleoperator remotely controls the android's behaviors by choosing its state. We also prepared a function that 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 be transferred together with mouth movement. If the speech and lip movements are not matched, people will not have a good impression of Geminoid HI-1's very human-like mouth. Therefore we control its mouth to match the teleoperator's mouth movements, which is measured by a motion capturing system.

Figure 4 illustrates our remote-controlled system. Two monitors display the room conditions, and one desktop computer is used by the teleoperator for remote control. In

Figure 3: System overview

addition, we have five optical cameras for motion capturing. In this way the teleoperator remotely controls Geminoid HI-1 (Figure 5).

4. EXPERIMENT

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 achieve 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 over a 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.

4.1 Method

4.1.1 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.

4.1.2 Conditions

There were three conditions:

G condition

The operator talked with participants through Geminoid HI-1 and controlled its motion to express nodding and looking behaviors (Figure 6, left).

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. The looking direction was calibrated in advance so that participants could feel that the person was looking at them (Figure 6, right).

S condition

The operator talked with participants through a speakerphone.

4.1.3 Operators for experiments

Two operators alternatively appeared who were not the original model for Geminoid HI-1. 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.

4.2 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

The degree to which the participant felt that the third person was present at the conversation.

Figure 4: Our remote-control system

Figure 5: View of remote operation system

Figure 6: Geminoid condition (left) and video conference condition (right)

Human likeness

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

Naturalness

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

Uncanniness

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

Responsiveness

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

Eye contact

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

4.3 Hypotheses 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:

With Geminoid HI-1, the operator is perceived as being 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 the strength of this factor for the android.

4.4 Results

Figure 7 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 7 show the significant differences of multiple comparisons at a 5% level of significance.

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

In the questionnaire, we asked about the participants' 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

We developed a remote-controlled android system that uses a very human-like robot called Geminoid HI-1. This system was developed to achieve the telepresence of a teleoperator. To verify the presence of this system, we conducted an experiment whose results confirmed that the 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, although the 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 as telecommunication systems, one important problem must be solved: uncanniness. Since the android gave a stronger 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 a stronger presence.

5.1 Remote-controlled android robot

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.

Figure 7: Participant impressions of three media: Geminoid android (G condition), video conference system (V condition), and speakerphone (S condition)

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 achieve ideal communication robots.

5.2 Uncanniness

We have proposed android science [15, 16], which aims to reveal humanness by developing a human-like robot that has a human-like appearance and behavior. Our system will be a suitable platform for such study. For now, the android was evaluated as highly human-like but uncanny (it is not as strong as the child android [16]), 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.

5.3 Where does human-likeness appear?

We employ a tele-operation function for our android system. A man who controls this system communicates with others through the system. This is a medium with a human-like appearance and performing human-like communication for a person who communicates with the android. But, where does the feeling of “human-likeness” appear? In the case of a fully autonomous system, how does a human feel that the system is a robot? At this time we cannot clarify this from our experimental results. And we doubt that the question will be clarified in the future. However, we believe that we have several advantages by using the androids for understanding communication between humans and machines. The system has a possibility that we have never before experienced.

Despite the fact that the android that we developed has a realistic human-like appearance, it is still an object. Anyone can control this robot. When a human who communicates with the android feels human-like intelligence or consciousness, how does he/she feel or what does he/she think? Ono developed an agent migration system called ITACO [17] and conducted an experiment to verify the effect of the agent migration from an agent to a robot. Their result showed that people treated the robot the same as before migration, if people felt the anthropo-

morphic agency of the agent from the interacting robot system.

How can human-robot interaction research, especially for androids with realistic human-like appearance, solve the kansei problems? We believe that this question reflects an important problem for science. We are going to treat that as a highly significant problem.

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