Designing simple and effective expression of robot's primitive minds to a human

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***Abstract*— This paper describes designing expression of robot's primitive minds in a simple and effective way. Although expression of robot's minds like internal states is becoming a major topic in human-robot interaction, few studies to propose a policy to design concrete expression. In this paper, we propose the design policy, called "SE2PM: Simple Expression to Primitive Mind", and fully implement expression of robot's minds based on the design policy, then investigate the effectiveness of them. SE2PM implies that intuitive and simple expression like beep sound from a simple robot (e. g. a mobile robot) is more effective than complicated behaviors from a complex robot (e. g. a dog-like pet robot) in informing its primitive minds to a human. Thus, in order to investigate the validation of our SE2PM policy, we implement two robots: a mobile robot based on Mindstorms with mind expression of beep sound, and a pet robot, AIBO, with mind expression of complicated behaviors. We also conduct a psychological experiment with participants to compare the two different expression, and the results eventually support SE2PM policy.**

I. Introduction

Home robots like Roomba[1], AIBO[2] have started to move out of robotics laboratories and into people's homes in recent years. Almost all of them are for entertainment to a user and the remaining ones are for a simple home task like rough sweeping by themselves. However home robots for a home task are expected to rapidly increase from now on because most of users never require just the entertainment and strongly need a robot to achieve various home tasks. In this situation, since a robot often can not achieve such a task by itself, it needs a way to ask a user to help it. For example, even though sweeping is a very simple home task, a robot can not remove a heavy obstacle like a chair or a table in order to sweep the floor under it, so a robot would ask user's help and a user would have to remove it for the robot.

The significant problem here is how to express the robot's internal state to a user. We call such an internal state the robot's *mind* because it may correspond to a human state of mind in the theory of mind[1]. We consider the expression should be designed depending on the robot's appearance because we intuitively think the appearance significantly influences human impression and interpretation of robot's expression. Although it is a important problem to design how a robot expresses and inform its mind to a human depending on the appearance, few studies on designing robot's expression in such a way have been done thus far. We are able to consider one of the simplest ways to express the mind is to use verbal communication with speech synthesis and it may be independent of a robot's appearance. However, such verbal communication significantly depends on natural language and needs additional equipment like a speech synthesis module. Hence we focused on nonverbal communication because psychological researches also show that nonverbal communication has rich information.

In this paper, we propose a policy to design expression of robot's mind depending on its appearance, called "SE2PM: Simple Expression to Primitive Minds", that means that a designer should design simple information with a simple appearance to express primitive robot's minds. We actually apply this SE2PM policy to express primitive minds of a robot with an appearance of a simple mobile robot implemented with LEGO Mindstorms, and design beep sound as simple expression. We consider this beep sound is a promising way to express primitive minds like negative, positive, and neutral because it was reported to be effective in human-computer interaction[7]. To compare with our proposed expression, we implement a pet robot, AIBO, which has a complicated appearance and can express its primitive minds by executing some complex behaviors with motion, light and sound. We investigate the effectiveness of SE2PM policy by a psychological experiment to compare the two robots with participants. Finally we obtain results to support our SE2PM policy and find out it is a valid policy to design expression of robot's primitive minds depending on the appearance.

Different types of social robots have been developed to assist with various tasks in our daily life[11][4]. In general, these robots have a particular appearance that is designed similar to that of humans or pet animals, i.e., beings that are familiar to us. Most humans who interact with these robots notice the familiarity of their appearances, and this makes it easier for them to communicate with these robots actively[2]. However, a robot's appearance should not be the sole focus; designing the robot's expressed minds to enable better communication with users is also important. Based on this concept, Ono and Imai[13] developed an interactive robot that can express behaviors associated with frustration when it encounters certain obstacles that interrupt its pathway.

[1]http://www.irobot.com/
[2]http://www.sony.net/Products/aibo/

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Mori pioneered relationship between a appearance and movement in a robot with the uncanny valley[10]. His uncanny valley described a robot becomes more uncanny as it becomes more similar to a real human. Although the uncanny valley does not directly imply SE2PM, the basic consideration is close to it. Duffy also discussed anthropomorphism of a robot with much insight[3], and he pointed out various important issues on relationship between anthropomorphism and a robot. In contrast with their studies, we propose the concrete design policy to express primitive minds, actually design them and verify the effectiveness.

Matsumoto *et al.* proposed a "Minimal Design" for interactive agents[9]; that is, agents should only have a minimalist appearance or express a minimal amount of information to users. In fact, they applied this minimal design policy in developing their interactive robots "Muu"[12] and life-like agent "Talking Eye" [15]. Moreover, Reeves & Nass showed in their "Media Equation" studies that anthropomorphized agents or computers might induce natural behaviors in humans, such as those that we direct towards other people[14].

Although the policies of minimal design and Media Equation are similar to our hypothesis that a detailed and likable appearance and expressed information are not vital for informing us of primitive minds, they lack a concrete strategy, like "which kinds of appearance should agents have" or "which kinds of information should agents express to users." In contract, our study provides a concrete strategy for designing interactive agents by clarifying the relationship between the agent's appearance and its expressed information so that the user understands these primitive minds.

Kanda et. al[5] investigated human behaviors to humanoid robots with two different appearances, ASIMO, Robovie, through a systematic psychological experiment with participant. As results, they found statistical significant difference in non-verbal behaviors like movement of arms, greeting motions, not in verbal behaviors. Their results are interesting, however they do not propose any design policy to express robot's minds.

II. SE2PM: Design policy to express robot's primitive minds to a human

We propose a policy to design expression of robot's minds depending on the appearance, called "SE2PM: Simple Expression to Primitive Mind". SE2PM means that a designer should design simple information from a robot with a simple (e.g. robot-like) appearance to express its primitive minds. On the other hand, this policy is based on the following hypothesis about the relationship between the robot's appearance and its expressed information on the user's understanding of primitive minds: *A robot with a human-like or animal-like appearance expressing complex and likable actions or behaviors is more confusing for users and is not really effective for conveying primitive minds. On the other hand, an agent with a more typical robot appearance conveying subtle expression[8], which show simple but intuitive information that can be more readily understood, is much more effective for informing users of the robot's primitive minds*(Fig. 1). If this hypothesis to support SE2PM was shown to be true, various interactive robots could be developed, ones that can interact naturally with users without the need for a huge budget to create a complex and likable appearance for these robots.

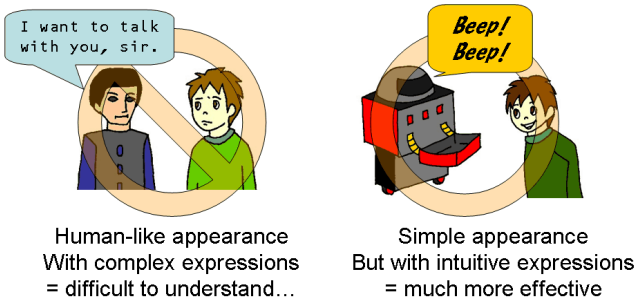

Fig. 1. Concept of our hypothesis about the relationship between robot's expressed information and its appearance.

III. Realizing SE2PM with beep sounds and mobile robot-like appearance

According to SE2PM, we are able to design actual expression and appearance of a robot for express primitive minds. In this study, we realize simple expression with beep sounds and simple appearance with a mobile robot-like appearance. This realization is based on the following reasons.

- *Beep sounds*: Komatsu[7] showed that people can estimate different primitive minds by means of simple beep-like sounds with different durations and inflections. He reported the following results.
  1) Sounds with decreasing intonation with shorter durations were perceived as a "positive mind."
  2) Sounds with increasing intonation regardless of its durations were perceived as a "negative mind."
  3) Flat sounds with longer durations were estimated as a "neutral mind."

  These beep sounds were simple but intuitive and effective information for the user to understand primitive minds. We applied these beep sounds as expressed information from robots that did not have a life-like appearance and behaviors.
- *Mobile robot-like appearance*: Mindstorms is a mobile robot, thus Mobile robot-like appearance is utilized without additional cost.

IV. Experiment

A. Overview

As already mentioned, our SE2PM hypothesized that a robot with a typical robot appearance expressing simple but intuitive information regarding primitive minds is much more effectively to users. We then conducted a psychological experiment to investigate this hypothesis.

Fig. 2. Three robots utilized in this experiment: AIBO, Mindstorms, and PC (from left to right).

1) Expressing Minds: We focused on the following three primitive minds as primitive and important ones for a user: negative, positive, and neutral. These three minds correspond to a valence value that is the basic dimension of complex emotions or affect[14]. These minds were briefly explained to the participants so that they would have a rough idea of how to recognize the minds.

- *Positive Mind*: Agreement, e.g., acceptance.
- *Negative Mind*: Disagreement, e.g., surprising, doubting.
- *Neutral Mind*: Hesitation, e.g., being lost for words.

These three primitive minds and interpretations were the same as the ones used in Komatsu's former study[7].

2) Appearance of robots: We utilized the following two robots as robots in our experiment. One was AIBO (ESR-7, SONY corporation). It is a robot that has a detailed and animal-like appearance and behaviors. The other was Mindstorms (Robotic Invention System 2.0, LEGO cooperation). It is an robot that has a typical robotic appearance like "Star Wars' R2D2." AIBO is one of the most famous consumer pet robots, and Mindstorms consists of LEGO blocks and Microcomputer modules. The user can then determine their preferred robot appearance by using various types of LEGO blocks. In addition, for a control, we utilized a normal laptop computer (Let's Note, W2 CF-W2DW6AXR, Panasonic corporation) that was utilized to express beep sounds in the former study[7]. The reason we utilized this laptop computer (PC) as a control was that it has a non-robot-like appearance compared with other robots (AIBO and Mindstorms). Fig. 2 shows the actual appearance of these three robots. They were nearly the same size.

3) Expressed Information: For expressing primitive minds to users, AIBO expresses already prepared dog-like behaviors, and Mindstorms and the PC express the beep sounds that were utilized in Komatsu's former study[7].

- *Expressing information of AIBO*: SONY prepared utility software called the "AIBO entertainment player" for AIBO users, which offers about 80 basic preset motions, like "cheer up" and "good morning." Among these motions, we chose the following six motions (two motions for each mind) that were similar to typical dog-like behaviors and accorded them with three primitive minds.
  - *Positive Mind*: "Happy 1" (wagging her tail cheerfully), "Happy 3" (blinking face LED expresses smiling face)
  - *Negative Mind*: "Angry 1" (howling action), "Unhappy 1" (moving her tail cheerlessly)
  - *Neutral Mind*: "Incline her head", "Wondering" (looking doubtful while moving her tail flatly)
- *Expressing information of Mindstorms and PC*: The following six beep sounds (two sounds for each mind) showed higher interpretation rates (more than 80%) in the former study in each of the minds.
  - *Positive Mind*: Two beep sounds with decreasing intonation (One is a duration of 189ms and a decreasing transition range in the F0 value between the onset and endpoint of 125Hz; the other is a duration of 418ms and a decreasing transition range of 125Hz)
  - *Negative Mind*: Two beep sounds with increasing intonation (One is a duration of 189ms and an increasing transition range of 125Hz; the other is a duration of 819ms and an increasing transition range of 125Hz)
  - *Neutral Mind*: Two beep sounds with a flat intonation (One is a duration of 639ms; the other is a duration of 819ms)

  These sounds were triangle waves generated by sound authoring software called "Cool Edit 2000," and they have the same F0 average of 131Hz.

Just before AIBO expressed these behaviors to participants, the experimenter said "Ready" to them, and then AIBO started expressing the selected behaviors. Before Mindstorms expressed these sounds, the experimenter started moving Mindstorms backward by about 5 cm and then forward by about the same distance. And before the PC expressed its sounds, the experimenter flashed its display. These actions were meant to tell the participants that the "stimulus is about to be expressed."

B. Participants

The participants were 18 Japanese university students (12 men and 6 women with a mean age of 21.2 years). All participants were not familiar with AIBO, Mindstorms, and other robots in general.

C. Experimental procedure

First, the experimenter gave participants the following instructions: "the purpose of this experiment is to evaluate the three robots by means of a questionnaire. Specifically, these robots express certain information that includes one of three primitive minds (positive, negative, and neutral), and your tasks in this experiment are to answer "which kinds of mind were included with the expressed information," and to tell us your impression of these robots in the questionnaire."

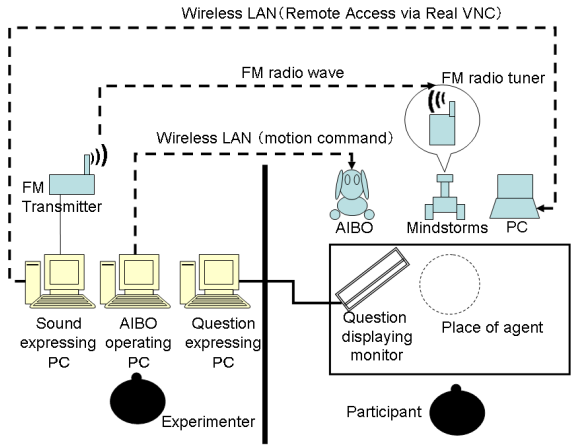

Fig. 3. Experimental settings.

Fig. 4. Actual experimental scene (a participant facing AIBO).

The experimenter locating behind the partition used a wireless LAN to make AIBO express its behaviors in front of participants. To make Mindstorms express its beep sounds, the experimenter played the sounds on a computer beside him, and then the sounds were transmitted as an FM radio wave. The FM radio tuner loaded on Mindstorms received this radio wave and played the received sounds to participants. For the PC, the experimenter remotely controlled it by means of "Real VNC remote access system," and he started playing the beep sounds at the appropriate time. The set up of the experiment is depicted in Fig. 3. Fig.4 is a photograph of the actual conditions in the experiment. A participant is facing AIBO.

When the robots expressed the behaviors or sounds to participants, the display placed in front of them simultaneously showed the following questions, "Did you feel that [***] was this robot's mind based on this presented information?"; [***] was the randomly selected mind among the three primitive minds. Participants were asked to answer YES or NO on

TABLE I

QUESTIONNAIRE ON IMPRESSIONS OF ROBOT

Q1: Did you understand the robot's minds?
Q2: Was the expressed information easily understandable?
Q3: Did you enjoy the way that the robot expressed its information?
Q4: Do you think that this robot can be part of our daily life?
Q5: Do you think that this robot has emotions?
Q6: Do you think that you can communicate effectively with this robot?

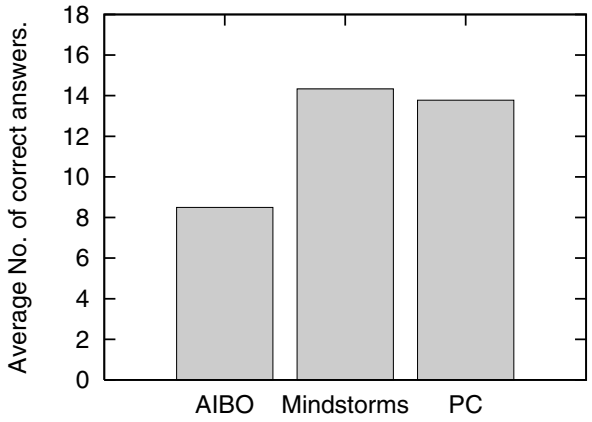

Fig. 5. Average numbers of correct answers for each robot.

the questionnaire. Specifically, each participant went through 18 trials (6 parts of information x 3 minds) for each robot. The order of presentation for the stimulus-question pairs was counterbalanced, and all participants were assumed to have contingent tendencies for judging each of the trials.

After finishing 18 trials with one robot, the participants were asked to fill in a questionnaire about their impressions of these robots. The questions are shown in table 1. After filling in this questionnaire, another 18 trials were conducted with the next robot, and then again with the last one. Thus, all participants worked with all three robots. The orders of robots (AIBO, Mindstorms, and PC) was also counterbalanced.

V. RESULTS

A. *Can participants estimate the robot's mind correctly?*

The average number of correct answers (within 18 trials) was calculated for each robot to determine whether or not the participants could estimate the robot's minds correctly. The results were that participants got an average of 8.50 answers correct with AIBO, 14.33 with Mindstorms, and 13.78 answers with the PC (5).

The results of an ANOVA showed significant differences between these three robots ($F(2, 52) = 39.71, p < .01(**)$), and an LSD test revealed that significant differences existed between AIBO and Mindstorms and between AIBO and the PC ($Mse = 4.6987, 5\%level$). Although the Mindstorms had a higher numbers of correct answers than the PC, no significant difference was found.

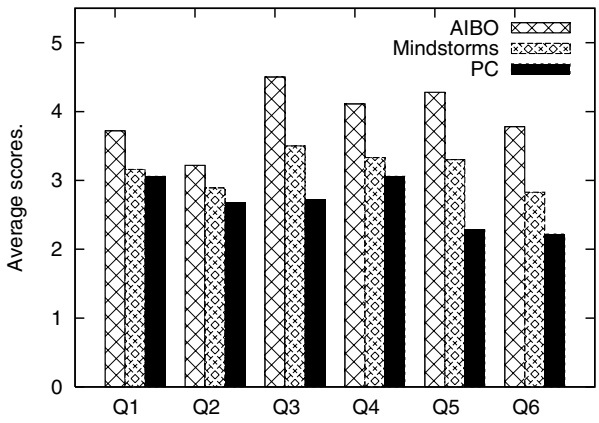

Fig. 6. Average scores for each question in questionnaire.

From these results, it is evident that using Mindstorms or a PC is a much more effective method of informing participants of a robot's minds compared with AIBO. Thus, these results support our hypothesis of SE2PM, which is, *a robot with a typical robot appearance expressing simple but intuitive information regarding primitive minds is much more effectively to users than a robot that has a life-like appearance expressing more complex and likable behaviors*. Although some concerns remain as to whether our hypothesis of SE2PM will stand up to further scientific analysis in an experiment, these results to support SE2PM will likely have a significant impact on the traditional design policy, which attempts to make the robot's appearance similar to those of humans or pets.

B. Subjective impressions of these robots

We investigated the impressions users had of these robots by means of a questionnaire that was completed for each of the robots after the trials. Our investigation involved the use of an ANOVA of each of the aforementioned questions, which were answered using a six point likert scale (With lower points indicating poorer assessment: one point was the worst assessment, and six points was the best).

The average scores in evaluating the different robots for each question are depicted in Fig.6. AIBO had the highest evaluations, and the PC had the lowest. However, the results of the ANOVA determined that four different relationships were present between the three robots.

1) Relationship A: AIBO received the highest overall evaluation: This relationship was observed in Q3 "Did you enjoy the way that the robot expressed its information?" and Q4 "Do you think that this robot can be part of our daily life?" Specifically, there were significant differences between AIBO and Mindstorms and between AIBO and the PC (Q3: $F(2,51) = 10.33, p < .01(**), Mse = 1.3845, 5\%level$, Q4: $F(2,51) = 4.38, p < .05(*), Mse = 1.2298, 5\%level$). These results stem from the fact that AIBO is already well known as a sophisticated robot for entertainment purposes.

2) Relationship B: AIBO received a higher evaluation compared with the PC: This relationship was observed in Q1 "Did you understand the robot's minds?" The only significant tendency was between AIBO and the PC ($F(2,51) = 3.16, p < .10(+), Mse = 0.7265, 5\%level$). However, the average number of correct answers for the PC's responses was significantly higher than that for AIBO, and it was nearly the same as that of Mindstorms. Thus, a significant gap was evident between the effectiveness of the actual function (informing participants of the robot's minds) and the participants' impressions of the robots.

3) Relationship C: Order of preference in the evaluation was AIBO, Mindstorms, and PC: This relationship was observed in Q5 "Do you think that this robot has emotions?" and Q6 "Do you think that you can communicate with this robot?" Specifically, significant differences were evident between these three robots (Q5: $F(2,51) = 23.64, p < .01(**), Mse = 0.7614, 5\%level$, Q6: $F(2,51) = 14.56, p < .01(**), Mse = 0.7492, 5\%level$). Here, AIBO received the highest evaluation, just as in relationship A. Moreover, Mindstorms received a higher evaluation than the PC.

4) Relationship D: No differences between the three robots: This relationship was observed in Q2 "Was the expressed information easily understandable?" ($F(2,51) = 1.04, n.s.$). Here, although AIBO received higher evaluations on most questions, there were no significant differences between the robots.

VI. Discussion

A. Coverage of SE2PM

We conducted psychological experiment to verify the effectiveness of SE2PM design policy, and the results eventually supported SE2PM. However these results are concerned with just case studies and just one example of various SE2PM realizations. Hence we need to discuss the coverage of the experimental results.

We consider the generality as to the following. First the results in this work show a concrete example that SE2PM-based robot design outperformed conventional one, with life-like and complicated appearance and expression, in expressing primitive minds. This also shows that another direction to design effective social robot without expensive appearance and actuators.

Second, by developing various simple expression based on SE2PM under a fixed robot-like appearance, the coverage of SE2PM can spread more an more. For example, we also developed and investigated a motion-based method to inform a user of robot's minds (e.g. a trouble with the front obstacle)[6]. In the work, a simple back-and-forth behavior of a robot with a simple mobile robot's appearance are shown effective. We can utilize this behavior as simple expression and extend simple expression of SE2PM.

B. What will the gap between user's impressions and mind estimation cause?

The results of the experiment clarified that the evaluations of AIBO in the questionnaires were mostly higher than those of the other robots. However the average number of correct answers in interpreting AIBO's basic behaviors were significantly lower. At a glance, the first set of results indicates that AIBO is an appropriate robot for communicating with users. However, these superiorities are derived from its well-designed appearance as a commercial product or from participants' superficial impressions, such as "AIBO is a famous, cute, and clever pet robot," not from the fact that its behaviors are easily understandable. Yet, a serious gap has been demonstrated between the high evaluation participants gave AIBO and its inability to inform participants of its primitive minds. Specifically, the results of Q1 in table 1 are an obvious piece of evidence for this gap; AIBO received its highest evaluation on Q1 "Did you understand the robot's minds?" even though most participants perceived AIBO's expressed information incorrectly. If these participants continued interacting with this robot, they would eventually notice the gap between its behavior and appearance, and then this gap might disappoint the participants and cause them to lose interest in communicating with it further. They would say something to the effect that "This robot looks very cute, but its behaviors are not really understandable..." An indication of this can be observed in the results of Q2 "Was the expressed information easily understandable?" No significant difference existed between the three robots on this item.

Mindstorms, the other robot used in our test, received a lower evaluation from participants. However, the average number of correct answers was significantly higher; that is, Mindstorms was better at informing participants of their primitive minds. If participants continuously communicated with it, they might notice that its behavior was more understandable, and subsequently, they might have a better subjective impression of the robot.

C. Influence of robot's appearance on users

In our experiment, Mindstorms and the PC expressed the same information (beep sounds) so that we could investigate the effects of the robots' appearance on the user's impressions and on their ability to estimate the robot's primitive minds.

In regards to estimating primitive minds, the average number of correct answers to Mindstorms' expression was somewhat higher than that to PC's ones. However, the differences were not significant. The participants' impressions of Mindstorms were significantly higher on the following two questions related to the participants' emotions: Q5 "Do you think that this robot has emotions?" and Q6 "Do you think that you can communicate with this robot?" These results were caused by the familiarity with the Mindstorms' robot-like appearance, compared with the PC, which did not have a robot-like appearance. However, this does not automatically mean that pursuing a familiar appearance increased the evaluations of participants.

VII. Conclusions

Various kinds of social robots have been developed to assist us with different tasks in our daily life. One of the most important issues in these studies is how to express the robot's primitive minds to a user for communication between them. This issue is strongly related to the robots' expressed information and its appearance. However few studies have investigated the relationship between these. Most studies applied human-like or animal-like appearance in the robots. In this paper, we proposed design policy of robot's expression of its primitive minds, SE2PM: Simple Expression to Primitive Mind, that means that a designer should design simple information with a simple appearance to express robot's primitive minds. To realize expression based on SE2PM, we designed mobile robot-like robot, Mindstorms, with simple beep sound. We conducted a psychological experiment to clarify effectiveness of SE2PM by using AIBO entertainment robots with likely behaviors and Mindstorms with beep sounds as simple expression. The results of our experiment supported SE2PM. Based on these results, we are able to create a design policy for simple and effective robots to interact with users.

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