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Action Sloping as a Way for Users to Notice a Robot's Function

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***Abstract*—This paper focuses on the problem that will arise in the near future from multi-function robots. Users will have to read thick operation manuals to use them. If users can use these robots without reading difficult manuals, it will improve user efficiency. We then proposed *Action Sloping* as a way for users to naturally recognize a robot's function. It provides the robots with gradual feedback signals when the user performs given actions. By changing the intensity of the feedback signal according to his/her action, it encourages him/her to perform an action that will trigger the robot's function. In our experiments, we made three kinds of feedback behaviors according to Action Sloping and one non-feedback behavior as the control condition. The participants of the experiment tried to find a robot's function and the latencies to first finding the triggered action were measured. An analysis of the latencies showed the difference between the sound feedback group by Action Sloping and the control group. This result showed that the effectiveness of Action Sloping was partially supported.**

I. Introduction

There has recently been an increase in research focusing on home robots [1]. For example, an autonomous lawn mower called Robomow[1] and an autonomous sweeping robot called Roomba[2] were developed for practical use. It is anticipated that these types of home robots will become increasingly sophisticated and have multiple functions similar to conventional home electric appliances. However, this will cause a usability problem. A robot with multiple functions will confuse its users because it will become difficult for them to comprehend all its functions. The user will also have difficulty reading their operation manuals upon introduction to them. Such problems are typically found in the latest mobile phones with multiple functions.

Some researches have proposed design methods for artifacts. Norman [2] has addressed the use of affordance [3] for artifacts design and Suchman [4] has analyzed users' behavior patterns for machines. Taking into consideration a users' automatic reaction to computers [5], [6] are also important for artifacts design. Yamauchi et al. have studied function imagery of auditory signals [7] and Japanese Industrial Standards employs the auditory signals on consumer products for elderly people guidelines [8]. In the Human-Agent Interaction research field, Ono et al. [9] have developed a technique for understanding a robot's internal state by improving the user's familiarity with the robot. Komatsu [10] has reported that users can infer a machine's internal state from its beeps. Kobayashi et al. have developed a method for expressing a robot's mind [11] and a method for controlling a robot in a more natural manner [12]. These researches have focused principally on the usage of artifacts.

Our approach to the human-centered robot design problem is to investigate users' awareness of robot functions. Awareness is one of the important factors for designing robots, especially when they have multiple functions. If users can easily notice a robot's functions without reading the operation manuals, they will reduce their workload and increase their operational efficiency.

In this paper, we analyze the relationship between user's actions and a robot's reaction in terms of the awareness of its function. To assist users in easily noticing a robot's functions, we propose "Action Sloping" as the way for robots to react against their actions. By applying Action Sloping to a robot, it provides gradual feedback to the users. In the experiments, we employed three types of behaviors according to the Action Sloping and applied them to a dog-like robot, and the participants were engaged in the task of finding the long-time-touch operation. The experimental results suggest that Action Sloping using a sound feedback behavior is effective in assisting users in noticing a robot's functions.

II. Action Sloping

In this section, we explain a way for users to notice a robot's function without reading manuals.

A. Function Awareness

When a user purchases home electric appliances or uses a machine for the first time, he/she reads the operation manuals before use to comprehend their functions. However, searching for the desired functions and studying how to operate the appliances are sometimes complicated tasks and for robots it would probably be even more difficult. Therefore, it would be ideal for a user to comprehend a robot's functions without reading the manuals. With this in mind, we then introduced *Function Awareness*, which is users' awareness of a robot's functions. This Function Awareness is achieved by a nonverbal interaction between a user and a robot. Fig. 1 shows a nonverbal interaction achieving the Function Awareness. We assume that a user and a robot exchange nonverbal information. Although it is possible to make robots express verbal information, this would be an experience similar to the manual reading for users. Therefore, we employed a nonverbal interaction. The interaction is composed of the following four steps.

1) The user makes gestures or body movements for the robot.

[1]http://www.frietndlyrobotics.com/robomow/
[2]http://www.irobot.com/

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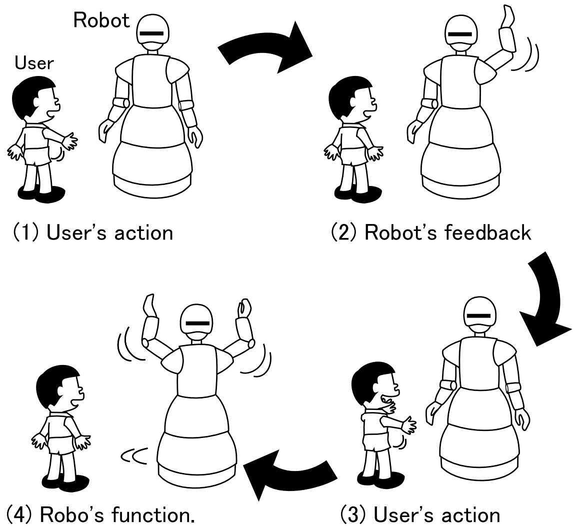

Fig. 1. Function Awareness.

2) The robot provides feedback signals.
3) The user performs more actions according to the robot's feedback.
4) The robot performs a function corresponding to the user's action.

According to this interaction, a user can easily notice the relationship between his/her actions and the robot's actions. We define this user awareness of the relationship as, Function Awareness.

B. Action Sloping for achieving Function Awareness

The key technology for achieving Function Awareness is how a robot helps a user easily understand its feedback signal and perform a particular action to trigger a function. Therefore, we propose *Action Sloping*, which is the way for a robot to change the intensity of its feedback signal according to user's action. Some of the feedback signals that can be employed are changing area the lighting area, a sound pitch, or the timing of a movement among others. Fig. 2 (a) shows the conventional method for providing a feedback signal. When a robot provides a feedback signal in the conventional way, the user notices its function by performing a triggered action. The triggered action is the user's action that triggers the robot's function. In this case, the user notices a behavior that the robot performs to execute a function as a feedback signal. If he/she performs actions other than the triggered actions, no feedback signal is provided and he/she will not notice the function. However, Action Sloping, showed in Fig. 2 (b), provides feedback signals even when the user performs actions other than the triggered action. Changing the intensity of a feedback signal according to his/her action will encourage him/her to perform the triggered action.

For example, imagine a housekeeping robot that performs a specific function, such as putting something away when the user places it at a certain distance from its sensors. In this case, the robot decreases the intensity of the light when the user places something like a washed dish to far from a designated point, and increases the intensity when the user places it to close to a designated point. Fig. 3 shows that the robot gradually changes the intensity of its feedback from low to high. Once the user observes the change, he/she can place the dish closer to the robot. This user's action causes the robot to put it away. Thus, the user can perform an appropriate action without reading the robot's manual.

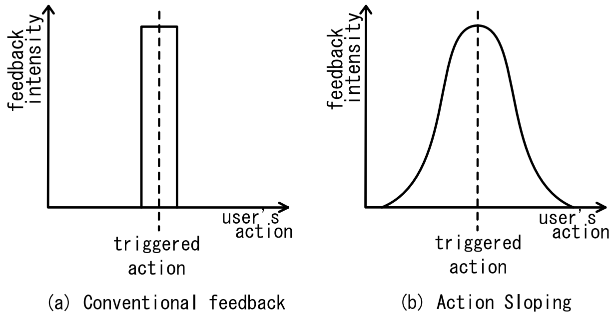

Fig. 2. Feedback Methods.

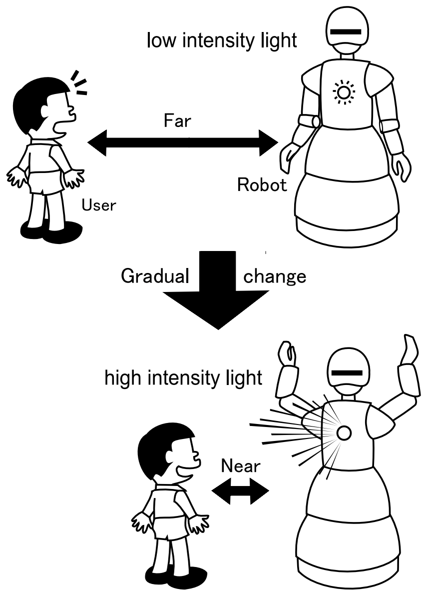

Fig. 3. Example of Action Sloping.

III. EXPERIMENTS

We performed experiments to investigate the effects of Action Sloping. Participants interacted with a robot that used Action Sloping. We measured the amount of time taken to find the robot's function. We compared the effectiveness of four feedback signals to which the Action Sloping was applied. The following information is the details from our experiments.

A. Robot

We used a dog like robot, Sony's AIBO ERS–7 (dimension: 180 $\times$ 278 $\times$319 mm; weight: 1.6Kg; color: white) shown in Fig. 4. It had 18 joints (4 legs: 3 joints and 1 paw each, 3 neck joints, 2 tail joints, 1 mouth joint), a wireless Ethernet, a video camera, a stereo microphone, a monaural speaker, 3 infrared sensors, 3 accelerometers, 28 LED lights and touch sensors (head, back, and chin). These sensors were updated every 32 msec. Fig. 5 shows the arrangement of the sensors.

Fig. 4. Sony AIBO (ERS–7).

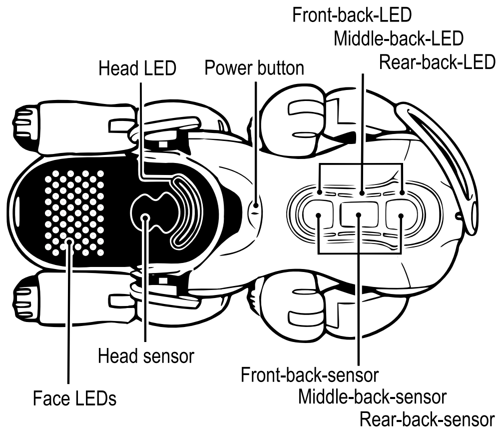

Fig. 5. Sensor arrangement of ERS–7.

We implemented it with the foreleg waving action, shown in Fig. 6. This function was performed when a participant touched the head of the robot for more than one second and then released his/her hand from it. The triggered action was *to touch the head for more than one second and release his/her hand*. This kind of operation provides efficient usage of the bottoms on electrical appliances and is implemented in mobile phones. The robot did not perform any action when the user performed actions other than the triggered action. We used the Tekkotsu framework [13] to implement the actions of the robot.

B. Action Sloping

We applied Action Sloping to the robot to encourage participants to perform the triggered action. Light, sound, and motion were employed as the feedback modality. Each

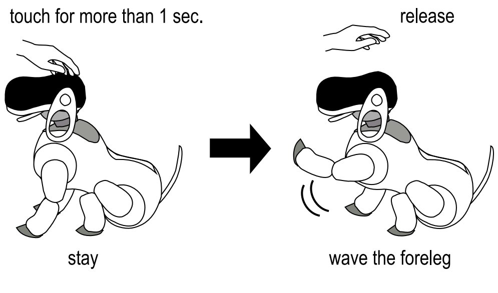

Fig. 6. Robot's Function.

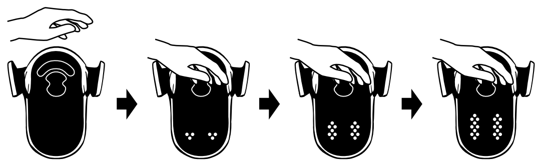

Fig. 7. Feedback by LED lighting.

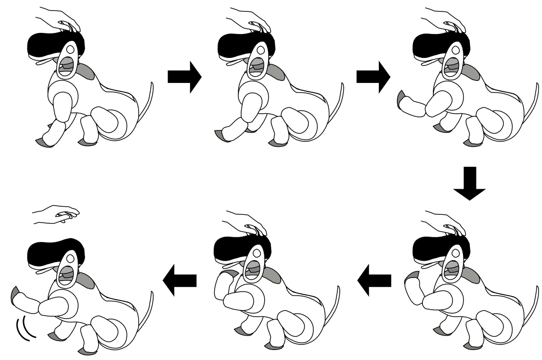

Fig. 8. Feedback by motion.

feedback signal was provided for participants while touching the head of the robot. These signals were provided for less than one second. The details are described as follows.

1) Light feedback: The robot increased the lighting area on its face, like that shown in Fig.7. When a participant touched the head, it lit six LEDs. If the user continued to touch for 0.5 sec, it increased the number of lighted LEDs from 6 to 14 and if they continued for 0.5 more sec, it increased the number of LEDs from 14 to 20. If he/she continued for more than 1.0 sec, it continued to light all LEDs. When they released their hand, it always turned off all LEDs.

2) Motion feedback: The robot performed part of the movements that achieved the function. Fig.8 shows the feedback method by motion. It performed a part of the foreleg lifting to express the progress of performing the function. The movement was performed according to the touch time. It began to lift the foreleg when the user touched the robot's head, and finished the motion and lowered the foreleg when they retracted their hand. If the user continued to touch the head for 1.0 sec, it maintained the final posture of the lifting.

3) Sound feedback: The robot made a sound when the user touched its head. The sound was a sine wave and the pitch was changed from 440 to 880 Hz according to the touch time. It began to make the sound when the user touched its head, and finished sounding and reset the pitch at 440 Hz when they released their hand. If the user continued to touch the robot's head for one second, it finished sounding.

We employed the ERS–7's own embedded feedback in addition to these Action Sloping feedback signals. It was difficult to remove the embedded feedback. Fig.5 shows the LEDs that were used for the feedback. A LED was lit when a participant touched a sensor that was placed near the LED; the head LED was connected to the head sensor and each back LED was connected to each back sensor. The LEDs were turned off if the user released their hand.

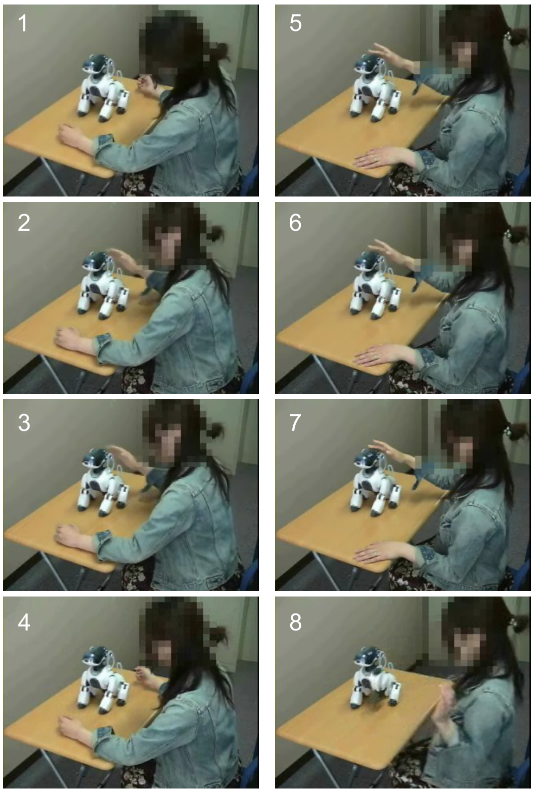

Fig. 9. Photographs of experiment.

TABLE I
TASK ACHIEVEMENT RATIO.

Condition	Ratio	
No feedback	60.0 %	(6/10)
LED	88.9 %	(8/9)
Motion	87.5 %	(7/8)
Sound	100 %	(9/9)

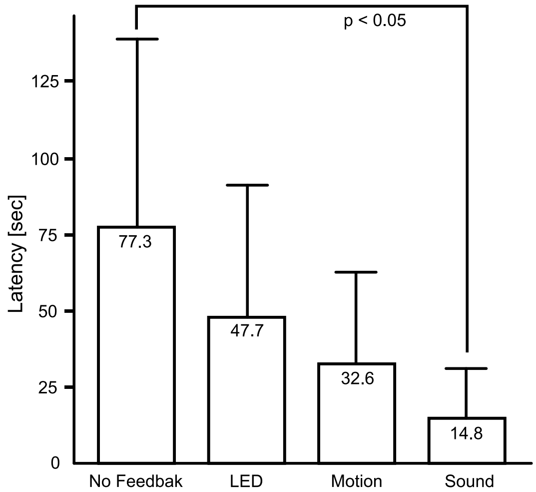

Fig. 10. Latency to first finding triggered action.

C. Participants

Thirty-six participants were divided into four experimental groups:

1) No feedback condition: ten men (mean age: 23.4 years, S.D. = 2.5 years).
2) Light feedback condition: seven men and two women (mean age: 21.8 years, S.D. = 1.1 years).
3) Motion feedback condition: eight men (mean age: 21.6 years, S.D. = 1.3 years).
4) Sound feedback condition: eight men and one woman (mean age: 21.7 years, S.D. = 0.9 years).

D. Method

The experiments were executed in a small chamber (W: 256 × D: 205 × H: 215 cm) at Kwansei Gakuin University. Each participant entered the chamber and interacted with the robot. A participant sat on a char in front of a desk. The robot was set on the desk facing sideways. The participants were instructed that (1) the robot didn't do anything of its own volition, (2) it did something when he/she did something, (3) they needed to find an action that would trigger the robot's action, (4) it had one action, and (5) the experiment was begun and finished when the experimenter gave a signal and continued for about five minutes. In addition, the participants were also instructed that (1) not to lift the robot up, (2) not to push it strongly, (3) not to remove its components, (4) not to forcibly move its joints, and (5) not to push the power switch. The experimenter left the chamber after they gave the start signal. Fig.9 shows some photos of an experiment.

E. Results

Table I shows the task achievement ratios. Four of the ten participants under the no feedback condition, one of the nine participants under the LED feedback condition, and seven of the eight participants under the motion feedback condition could not find the triggered action within the time limit. All the participants under the sound condition could find the triggered action.

The average latency that was the time from the first touch on the robot's head until the robot first waved its foreleg is shown in Fig.10. The average time was calculated without the participants who could not find the triggered action. The overall difference in the latency to first finding the triggered action among the four groups was significant ($F_{3,26} = 3.23, p < 0.05$). The difference between the no feedback condition and the sound condition was significant (Tukey's HSD test, $p < 0.05$). We confirmed that sound was the most efficient way to help participants find the triggered action.

Fig.11, 12, 13, and 14 show the participants' behavior patterns for touching the head under the no feedback, LED, motion, and sound conditions respectively. In the figures, each line represents a participant, and the line includes the information about the start and finish times, and the cumulative duration of the touching of its head. The vertical axis represents the cumulative duration for the robot's head being touched, and the horizontal axis represents the time. The solid lines and the broken lines in each figure are used to distinguish a line from another crossing line. We find that the horizontal change of lines under the no feedback and LED conditions are bigger than those under the motion and sound conditions.

Fig.15 shows the averaged ratio of the duration of touching the robot's head within the latency boundary. The

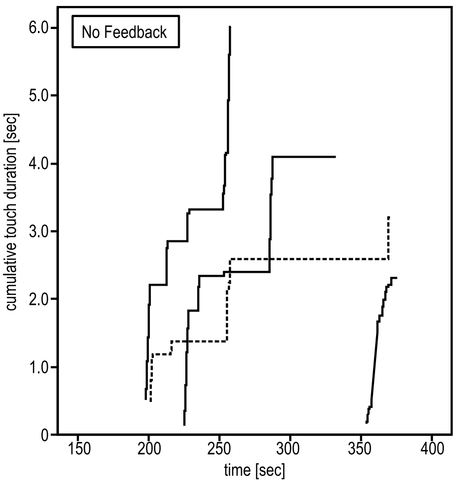

Fig. 11. Pattern of Touching Robot's Head under No Feedback Condition.

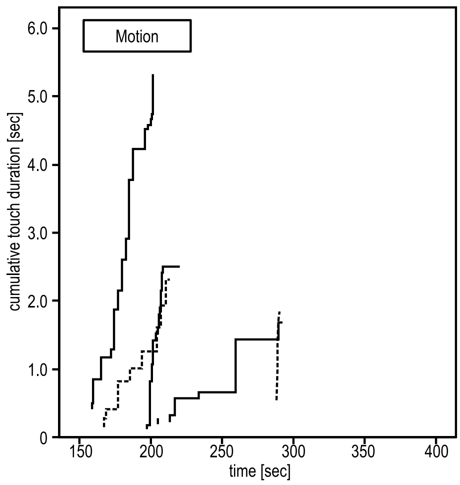

Fig. 13. Pattern of Touching Robot's Head under Motion Condition.

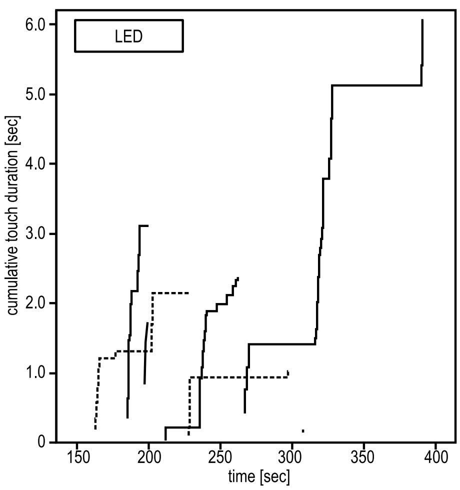

Fig. 12. Pattern of Touching Robot's Head under LED Condition.

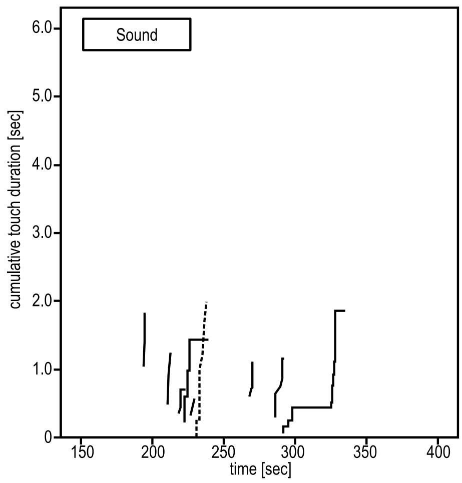

Fig. 14. Pattern of Touching Robot's Head under Sound Condition.

overall difference in the ratio among the four groups was not significant ($F_{3,26} = 0.29, p = 0.83$). We found that the participants were engaged in touching the head about 30% of the latency time. Fig.16 shows the averaged frequency of touching the robot's head within the latency boundary. The participants under the motion and sound conditions touched the robot's head once every two seconds, and the participants under the no feedback condition touched the robot's head once every four seconds. However, the overall difference in the frequency among the four groups was not significant ($F_{3,26} = 1.60, p = 0.22$).

IV. Discussion

A. Effectiveness of Action Sloping

The effectiveness of Action Sloping was partially supported by the experimental results. We thought that Action Sloping would be an effective way to make general guidelines for designing manual-free robots. However, the experimental results showed that statistically only the sound condition was significantly faster at assisting in the participants' triggered action than the no feedback condition. Comparing the behavioral patterns among the conditions, we found that the participants under the sound feedback condition obviously performed differently from the others. We need to clarify why sound is the most effective means of recognition.

There is a study about the effect of sound made by a computer. Komatsu [10] has reported that users can infer the attitudes of a computer by listening to its chirping sounds. Changing the pitch of the sound might lead the participants' to a triggered action. It is necessary to perform additional experiments using some kind of chirping sound to confirm the effect of Action Sloping.

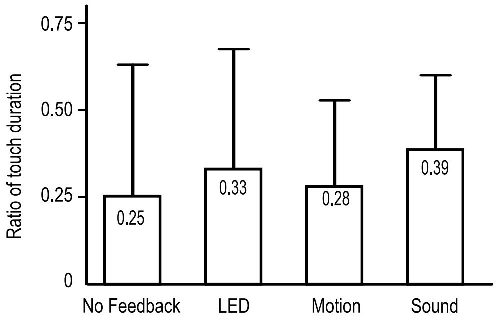

Fig. 15. Ratio of Touch Duration.

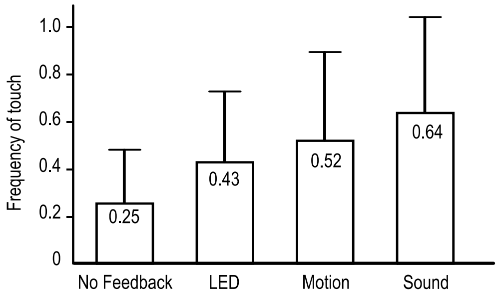

Fig. 16. Frequency of Touch.

The latencies of first finding the triggered action under the LED, motion, and sound conditions were shorter than those for the no feedback condition. This result corresponded to the importance of quick feedback for the users [2]. However, the most effective modality was different from that of a previous study [11]. That study showed that the motion of the robot was the most effective way to lead to a user's action for a robot. In contrast, this work showed that sound was the most effective modality. The two studies used different robots, participant's tasks, and experimental environments. We found that the biggest difference was the tasks. The participants in the previous study were instructed to help a robot, and the participants in this study were instructed to find a robot's function. The participants in the previous study knew the function of the robot. If the knowledge of the robot's function is taken into consideration, we think that motion feedback would be the most effective way, because the users would know the robot's functions, and that sound would be effective when they do not.

B. Experimental environment

The conditions of the experiments were different from that of the real world. We did not permit participants to lift the robot. The purpose of this restriction was to avoid handling it roughly. They might frequently perform certain actions instead of lifting it in the experiments. Therefore, the latencies we obtained would be different from a real world situation without such restrictions. However, the relative differences among the modalities should be universal because other conditions were the same.

The experimental situation was similar to playing with the robot because we instructed participants to find the robot's function. Such situation will be suited for a robot that has the ability to help users and to play with them. Users will not try to find a robot's unknown functions during a progression of the operation. However, applying the aspect of entertainment, it will improve sociability of robots and make situations similar to this one.

The problem with these experiments was that the robot had the single function. Situations in which the robot has multiple functions will be more natural and realistic. To improve Action Sloping and develop practical robots, it is necessary to perform experiments using a robot with multiple functions.

V. Conclusion

When robots have a lot of functions, users will have to read thick operation manuals to use them. If users can use robots without reading the manuals, it will improve their efficiency. Therefore, we propose Action Sloping as a way for users to notice a robot's functions. It provides gradual feedback signals when the user performs actions. Changing the intensity of the feedback signal according to the user's actions encourages them to perform actions that trigger the robot's function. For the experiments, we made three kinds of feedback behaviors according to Action Sloping and one no feedback behavior as the control condition. The participants of the experiment tried to find a robot's function and the latencies for first finding the triggered actions were measured. An analysis of the latencies showed the difference between the sound feedback group by Action Sloping and the control group. This result showed that the effectiveness of Action Sloping was partially supported. We are planning additional experiments to clarify why sound is the most effective way. When it is clear, we will improve the method for users to notice a robot's function.

Acknowledgment

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