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Action Sloping for Increasing Awareness of Robot's Function

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Abstract – In the near future, users of multi-function robots will have to read thick owner's manuals to use them. If users can use these robots without reading difficult manuals, it will improve user efficiency. We propose *Action Sloping* as a way for users to naturally understand a robot's function. This concept programs robots with feedback behavior that gradually changes in intensity as the user carries out given actions. By changing its feedback behavior in response to a user's actions, a robot encourages him or her to perform an action that will make the robot function. We conducted two experiments in which we programmed a robot dog with three patterns of feedback behavior based on the Action Sloping concept and two patterns not based on it as control conditions. The participants in the experiments tasked with identifying the robot's function, and the identification latency times were measured. The results showed that, as compared to the non-feedback conditions, only a chirping sound condition significantly assisted the participants in identifying the triggering action. These findings partially supported the effectiveness of the Action Sloping concept.

Keywords : human-robot interaction, feedback design, function awareness, action sloping

1. Introduction

There has recently been an increase in research on robots for the home [1]. For example, an autonomous lawn mower called Robomow [1] and an autonomous sweeping robot called Roomba [2] have been developed for practical use. If these home robots become more sophisticated, they will have multiple functions just as conventional home appliances have. They will become more difficult to use. Robots with multiple functions will confuse users with their multiplicity of functions. Users will have the same difficulties reading the robot owner's manuals as they currently have with manuals for the latest mobile phones with multiple functions.

Some researchers have proposed design methods for artifacts. Norman [2] has addressed the use of affordance [3] for artifact design. Suchman [4] has analyzed users' behavior patterns in relation to machines. Kobayashi et al. have developed a more natural method for users to control robots in a cooperative task [5]. These studies have focused principally on usage of artifacts.

Our approach to the human-centered robot design problem is to investigate users' awareness of robots' functions. User awareness is an important consideration in robot design, especially when robots have multiple functions. If users can easily grasp a robot's functions without reading its owner's manual, they will be able to operate it more easily and efficiently.

We consider that appearance of a robot, use of affordance, social relationships between a user and a robot, and feedback information from a robot play an important role when users notice robot's functions without reading manuals. If a robot had dog like appearance, users deal with the robot in the same way to a real dog (e.g. users tend to stroke a dog's head as positive reward) [6]. Users inevitably build a model from the appearance when they face a robot, and act according to the model [7]. Kiesler et. al investigated influence of various users' personal traits to their behaviors to a robot [8]. Robots' physical presence effect [9], influence of negative attitudes to robots [10], and users' automatic reactions to computers [11], [12] are also important information for user awareness. As an application of social relationships between a user and a robot, Ono et al. have developed a technique for familiarizing users with a mobile robot [13].

Some researchers have dealt with designing feedback signals. Yamauchi et al. have studied function imagery of auditory signals [14] and Japanese Indus-

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2: http://www.irobot.com/

trial Standards uses auditory signals on consumer products to guide elderly users [15]. Komatsu [16] has reported that users can infer a machine's internal state from the beep sound it makes. Kobayashi et al. have developed a method with which robots can express themselves in a sweeping task [17].

We focus on feedback signals that a robot provides. The appearance, affordance, and social relationships can provide users with background knowledge, but we do not deal with them. Based on robot's feedback signals, users will dynamically change their actions and notice its functions. The previous studies about feedback information described above do not discuss the user awareness of robots' functions. As a first step for realizing manual free robot, we investigate some simple feedback signals by a robot to clarify the effect for users' future actions.

In this paper, we analyze the relationship between a user's actions and robot's reactions in terms of user awareness of the robot's functions. To assist users in understanding a robot's functions, we propose *Action Sloping* as the way for robots to react to user actions. Applying Action Sloping to a robot dog provides gradual feedback to the users. We conducted two experiments using three patterns of feedback behavior based on the Action Sloping concept and two patterns not based on it as the control conditions. The results showed that Action Sloping using a chirping sound was effective in familiarizing users with a robot's functions.

2. Action Sloping

2.1 Function Awareness

When a user purchases a home appliance or uses a machine for the first time, he or she reads the owner's manual before using it to understand its functions. However, searching for the desired functions and studying how to operate the appliances can be complicated and difficult, and for robots, it would probably be even more difficult. Therefore, having a way for a user to comprehend a robot's functions without reading the manuals would be useful. With this in mind, we introduced the concept of *Function Awareness*, which is users' awareness of a robot's functions and is based on nonverbal interactions between a user and a robot.

We assume that a user and a robot exchange nonverbal information. Although it is possible for robots to express information verbally, this would be virtually the same experience as reading a manual. If a robot provides verbal information for a user to notice its functions, it repeatedly says the same explanation for each button or sensor. This will disgust the user. To describe text explanation on a robot's body is also difficult because of the limitation of the writing space. In contrast, nonverbal information will provide cues for user to notice a robot function, and can be easily neglected if they do not need them. Therefore, we focused on nonverbal interaction composed of the following four steps as a user aid.

1. The user gestures to the robot.
2. The robot exhibits feedback behavior.
3. The user responds to the robot's feedback.
4. The robot performs a function in response to the user's action.

Based on this interaction, a user can easily notice the relationship between his or her actions and the robot's actions. We call this user awareness of the relationship Function Awareness.

2.2 Action Sloping as a Method of Achieving Function Awareness

The key to achieving Function Awareness is how a robot helps a user understand its feedback behavior and take a particular action to trigger a function. We propose *Action Sloping*, in which a robot changes the intensity of its feedback behavior in response to a user's action. By intensity of behavior, we mean the volume, frequency and quality of representation that the robot provides. Some patterns of feedback behavior that can be used are changing lights displayed, sounds emitted, or timing of movements. Fig. 4.2 (a) shows the conventional method for exhibiting feedback behavior. When a robot exhibits feedback behavior, the user responds to its behavior by taking a specific action. This action triggers the robot's function. In this case, the action that the robot takes to execute a function is conveyed to the user as feedback behavior. If the user takes actions other than the triggering actions, the robot does not exhibit feedback behavior and the user will not notice the function. However, with Action Sloping, shown in Fig. 4.2 (b), the robot exhibits feedback behavior even when the user takes actions other than the triggering action. Changing the intensity of feedback behavior in response to the user's action, the robot will encourage the user to perform

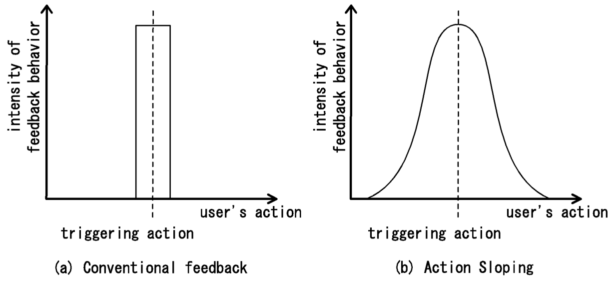

Fig. 1 Intensity of Feedback Behavior.

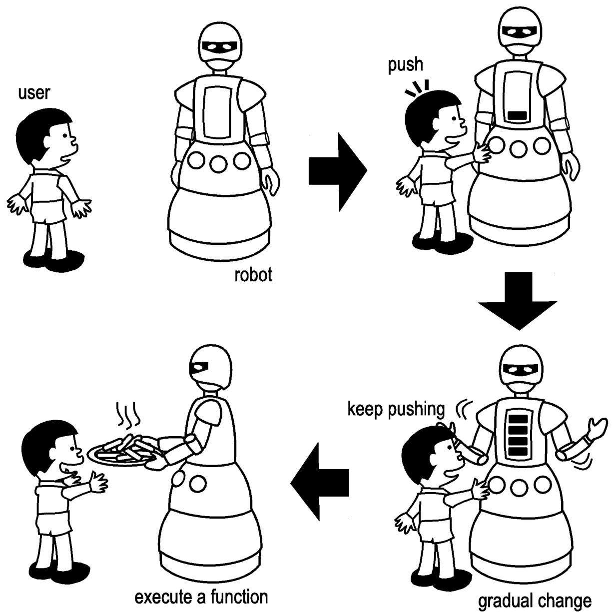

Fig. 2 Example of Action Sloping.

the triggering action.

For example, imagine a housekeeping robot that performs a specific function, such as cooking or dish washing. Fig. 2 shows a cooking robot that interacts with a user. When a button is pushed for few seconds, the robot provides food to the user. If the button is pushed by mistake, it can avoid interrupting the task that the robot is engaged in. However, it is difficult for the user to know that he or she should push the button for few seconds if he or she hasn't read the robot's manual. Action Sloping attempts to solve this problem by providing gradual feedback and encouraging users to keep pushing the button. When the robot provides food for the user, the user will notice the triggered action. Thus, the user can take appropriate actions without reading the robot's manual.

3. Experiments

We conducted two experiments in which participants interacted with a robot equipped with Action Sloping to investigate its effects. We measured the amount of time taken to identify the robot's function. In the first experiment, we compared the time required to identify functions using four patterns of feedback behavior. In the second experiment, we added a fifth pattern of feedback behavior and compared the effectiveness of the five patterns of feedback behavior.

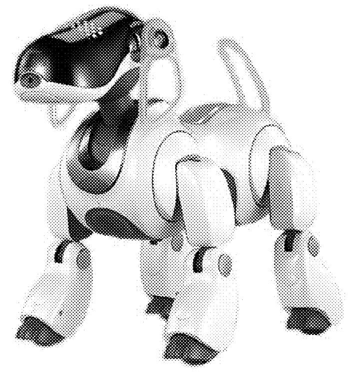

Fig. 3 Sony AIBO (ERS–7).

3.1 Experiment 1: Four Groups Comparison

We designed three kinds of feedback behaviors based on the Action Sloping and one non-feedback behavior as a control condition. We programmed a robot dog with these behaviors. Following are the details of the experiment.

3.1.1 Robot

We used a robot dog, Sony's AIBO ERS–7 (dimension: 180 × 278 ×319 mm; weight: 1.6kg; color: white), which is shown in Fig. 3. AIBO ERS-7 has 18 joints (4 legs with three joints each, three neck joints, two tail joints, and one mouth joint), a wireless Ethernet, a video camera, a stereo microphone, a monaural speaker, three infrared sensors, three accelerometers, 28 LED lights, and touch sensors (head, back, and chin). These sensors were updated every 32 msec. Fig. 4 shows the sensor configuration.

We programmed the robot to wave its foreleg, as shown in Fig. 5. It did this when a participant touched its head for more than a second and then took away his or her hand. That is, the triggering action was *to touch the dog's head for more than a second and then take away the hand.* This kind of operation, pushing a button long is programmed in numerous mobile phones to assign multiple functions to a button. The robot took no action when the user did things other than the triggering action. We

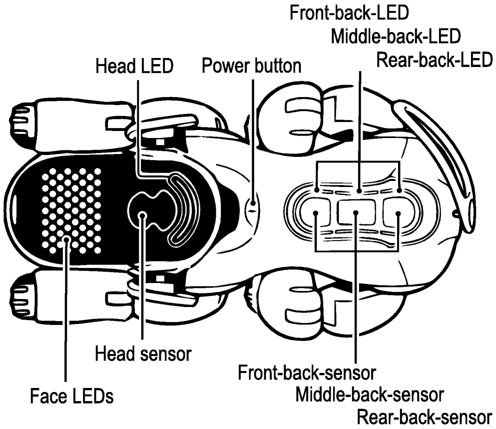

Fig. 4 Sensor Configuration of ERS–7.

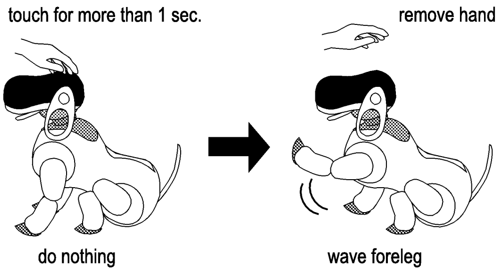

Fig. 5 Robot's Function.

used the Tekkotsu framework [18] to implement the actions of the robot.

It is difficult for users to find this kind of operation without reading manuals. Therefore, we evaluate Action Sloping by investigating the ease of noticing such operation.

3. 1. 2 Action Sloping

We equipped the robot with Action Sloping capabilities to encourage participants to perform the triggering action. Light, sound, and motion were used as feedback modalities. Each pattern of feedback behavior was exhibited for participants while they touched the robot's head. These patterns were exhibited for less than one second.

• Light feedback:

More of the area on the robot's face lit up in response to certain actions, as shown in Fig.6. When a participant touches the robot's head, six LEDs lit up. If the user continues to touch its head for 0.5 sec, the number of lighted LEDs increases from 6 to 14 and if he or she continues for 0.5 more sec, the number of LEDs increases from 14 to 20. If the user continues for more than 1.0 sec, all LEDs stay lit. When the user removes his or her hand, all LEDs turn off.

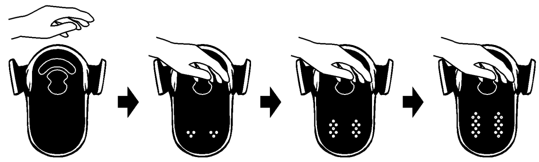

Fig. 6 LED Lighting Feedback.

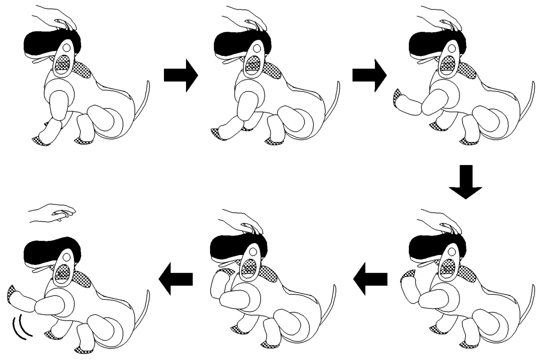

Fig. 7 Motion Feedback.

• Motion feedback:

The robot performed part of the movement involved in the function. Fig.7 shows the motion feedback modality. It lifts part of its foreleg to express progress toward performing the function. The robot moved its leg depended on the amount of time it was touched. It began to lift its foreleg when the user touched its head and finished the motion and lowered the foreleg when the user retracted his or her hand. If the user continued to touch its head for 1.0 sec, it maintained the final posture with its foreleg up.

• Chirping sound feedback:

The robot also made a sound when the user touched its head. The sound had a sine wave pattern whose pitch changed from 440 to 880 Hz according to the touch time. It began to make the sound when the user touched its head, and stopped making the sound and reset the pitch at 440 Hz when the user removed his or her hand. If the user continued to touch the robot's head for one second, it stopped making the sound.

We used the ERS–7's own embedded feedback in addition to the Action Sloping feedback behaviors. It was difficult to remove the embedded feedback. Fig.4 shows the LEDs that were used for the feedback. An LED lit up when a participant touched a sensor located near the LED; the LED in the head was connected to the head sensor and each LED in the dog's back was connected to a sensor in its back.

The LEDs turned off if the user removed his or her hand.

3.1.3 Participants

Thirty-seven participants were divided into four experimental groups:

1. Non-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 and one woman (mean age: 21.3 years, S.D. = 1.5 years).
4. Chirping sound feedback condition: eight men and one woman (mean age: 21.7 years, S.D. = 0.9 years).

3.1.4 Method

The experiments were conducted in a small room (W: 256 × D: 205 × H: 215 cm) at Kwansei Gakuin University. Participants entered the room, sat on a chair in front of a desk, and interacted with the robot. The robot was placed on the desk facing sideways. The participants were instructed that (1) the robot wouldn't do anything of its own volition, (2) it would respond when he or she did something, (3) that they needed to find an action that would trigger an action by the robot, (4) that the robot was only programmed for one action, and (5) that the experiment began when the experimenter gave a signal and continued for about five minutes. In addition, the participants were instructed (1) not to lift the robot up, (2) not to push it hard, (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 room giving the start signal. Fig.8 shows photos of a participant interacting with the robot.

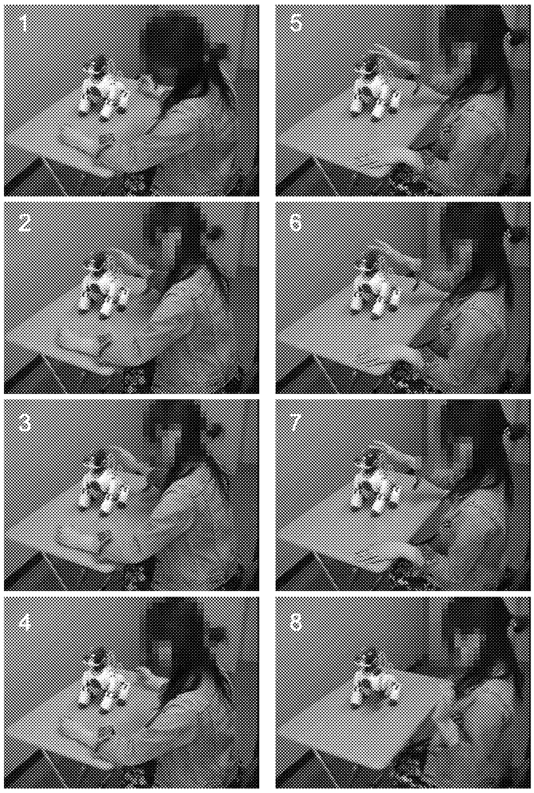

Fig. 8 Photographs of Experiment.

Table 1 Task achievement ratios.

Condition	Ratio
No feedback	60.0 % (6/10)
LED	88.9 % (8/9)
Motion	88.9 % (8/9)
Chirping sound	100 % (9/9)

We measured the amount of time before they notice the robot function for evaluating the ease of function awareness. It is possible to ask them to report an identified function when they think they find it. However, there is a risk of their confusing a feedback signal with a robot function. Therefore, we employ the objective method in our experiments.

3.1.5 Results

Table 1 shows the task achievement ratios. Four of the ten participants in the non-feedback condition, one of the nine participants in the LED feedback condition, and one of the nine participants in the motion feedback condition were not able to identify the triggering action within the time limit. All the participants in the chirping sound condition were able to identify the triggering action. The difference in the achievement ratios among the four groups was not significant ($\chi^2 = 6.25$, d.f.=3, $p = .10$). The task achievement ratios were affected by the experimental time limit. If the time limit is set at three minutes, the difference might be statistically significant. This result showed that there was no significant difference under the five-minute time limit.

The average latency time for identifying the triggering action is shown in Fig.9. The latency time was the amount of time from when a participant first touches on the robot's head till when the robot first waved its foreleg. The participants who could not identify the triggering action were not included in the calculation of average latency time. We rejected one woman as an outlier because her latency time was longer than the average + 2SD.

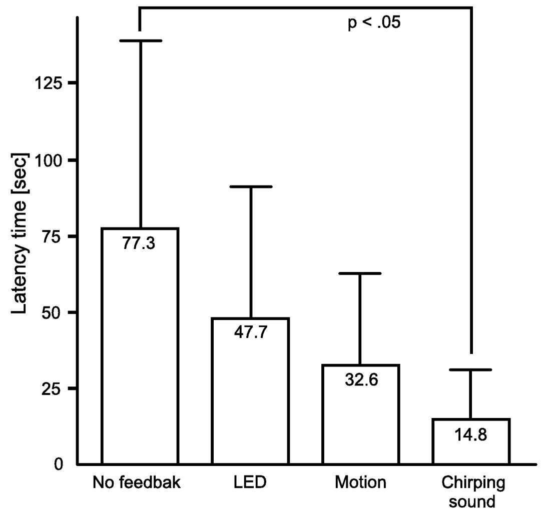

Fig. 9　Latency time.

The overall difference in the latency to time among the four groups was significant ($F_{3,26} = 3.23, p < .05$). The difference between the no-feedback condition and the chirping sound condition was significant (Tukey's HSD test, $p < .05$). We confirmed that sound was the most efficient way to help participants find the triggering action.

Multiple-regression was used to determine the variations between elapsed time and touch duration within the participants [19] in each group. Elapsed time is amount of time that participants engage in an experiment. Touch duration is amount of time that they continue to touch on the robot's head in a touch. We used touch duration as outcome variable, elapsed time and the participants as predictor variables. Participant was treated as categorical factor using dummy variable. The p value from the t test for the regression slope of elapsed time was used to determine the probability of the analysis. The magnitude of correlation coefficient between elapsed time and touch duration within participants was calculated as square root of (sum of squares for elapsed time) / (sum of squares for elapsed time + residual sum of squares). The sign of the correlation coefficient was given by that of the regression coefficient for elapsed time.

Determining the variations within the participant, the positive correlation with correlation coefficient of .381 was found between elapsed time and touch duration in the chirping sound condition ($p < .05$). Table 2 shows the correlation coefficients between touch duration and elapsed time. We found that the touch duration for the participants in the chirping sound condition gradually became longer. However, it was not clear whether Action Sloping caused participants to touch longer. We conducted the second experiment to answer this question.

Table 2　Correlation between touch duration and elapsed time.

Condition	c.c.	p	d.f.	t
No feedback	.108	.436	52	0.785
LED	.0629	.570	82	0.571
Motion	.226	.0990	52	1.680
Chirping sound	.381	.0314*	30	2.257

c.c.: correlation coefficient
d.f.: degree of freedom

3.2　Experiment 2: Five Groups Comparison (add a fifth pattern)

In the experiment 1, the difference between the non-feedback condition and the chirping sound condition was significant. However, it is not clear whether the major factor is the auditory signal or pitch changing by Action Sloping. We add a sinusoidal sound condition whose pitch was fixed to 440 Hz as an auditory signal without Actions Sloping. The robot and the experiment conditions were identical to those of the first experiment. Following are details of the experiment.

3.2.1　Sinusoidal sound feedback

The robot made a sound when the user touched its head. The sound was a sine wave whose pitch was 440 Hz. The robot began to make the sound when the user touched its head, and stopped making it when the user removed his or her hand. If the user continued to touch the robot's head for one second or more, it stopped making the sound.

3.2.2　Participants

Nine men and two women (mean age: 21.4 years, S.D. = 1.6 years) participated in the experiment.

3.2.3　Results

Table 3 shows the task achievement ratios of the sinusoidal sound condition. Three of the eleven participants in the sinusoidal sound feedback condition could not identify the triggering action within the time limit. The difference in the achievement ratios among the five groups was not significant ($\chi^2 = 6.26$, d.f.=4, $p = .18$).

Fig. 10 shows the average latency time, including the latencies for the first experiment's conditions.

Table 3 Task achievement ratios.

Condition	Ratio
Sinusoidal sound	72.7 % (8/11)

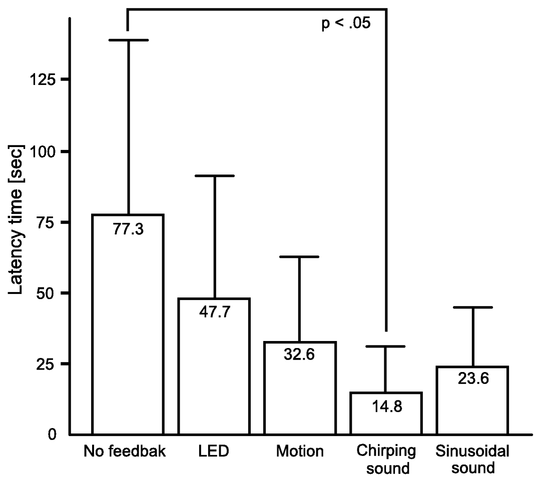

Fig. 10 Latency Times.

Table 4 Correlation between touch duration and elapsed time.

Condition	c.c.	p	d.f.	t
Sinusoidal sound	.0478	.776	36	0.287

c.c.: correlation coefficient
d.f.: degree of freedom

We rejected one man as an outlier because his latency time was longer than the average + 2SD.

The overall difference in the latency times among the five groups was significant ($F_{4,32} = 3.08, p < .05$). The difference between the non-feedback condition and the chirping sound condition was significant (Tukey's HSD test, $p < .05$).

Determining the variations within the participant, no correlation with correlation coefficient of .0478 was found between elapsed time and touch duration in the sinusoidal sound condition (Table 4). The touch duration of the sinusoidal sound did not gradually become longer. We found that changing the sound pitch encouraged the participants to gradually increase how long they touched the robot's head.

4. Discussion

4.1 Effectiveness of Action Sloping

We confirmed that the chirping sound was the most effective way of helping participants identify the triggering action and showed a positive correlation between the touch duration and elapsed time. With the sinusoidal sound there was no correlation between the touch duration and elapsed time. This result showed that changing the pitch of the sound helps users identify unknown robot functions. The results indicated that Action Sloping was effective. We thought that Action Sloping would be an effective way of setting general guidelines for designing manual-free robots. However, the experimental results showed that statistically only the chirping sound significantly assisted participants in identifying the triggering action as compared the non-feedback condition.

Marila et. al employ auditory and visual feedback signals in their experiments on mobile phone interface. These feedback signals are used to notify that the system automatically change the user interface from one mode to another when time-out occurs. In the experiments, they measured response time (RT) from the time-out occurrence to the time of a user's action in text entry task. The result showed that auditory feedback enabled faster RTs than visual feedback. Their results are similar to ours in auditory feedback domination. However, they did not discuss the effect of pitch changing.

Why was the chirping sound effective? There are studies about the effects of sound on human beings. Komatsu [16] reported that users were able to infer the attitudes of a computer by listening to its sounds. He showed that the users inferred from a sound increasing in pitch that the computer had a positive attitude and from a sound decreasing in pitch that it had a negative attitude. Moreover, Ohala [20] found that high fundamental frequency in intonation signifies smallness, a non-threatening attitude, and desire for goodwill of the receiver and low frequency conveys largeness, threat, self-confidence, and self-sufficiency. With these studies in mind, we thought that the participants of our experiments might interpret a chirping sound as a positive, submissive attitude on the part of the robot. Although we did not investigate the behavior of users who are provided a sound whose pitch was changed to lower, the sound will not contribute significantly to identifying the triggering action.

Nass et. al describe that human emotions are recognized through vocal properties [21]. Especially, raising pitch expresses happiness. The effect of robot's emotion will be demonstrated through questionnaires on participants' emotions and attitudes for each feedback signal in future work.

Our results showed that the most effective modality was different from that of a previous study [17]. That study showed that a robot's movements were the most effective way of helping a user interacts with a robot. In contrast, this study showed that sound was the most effective modality. The two studies used different robots, participant tasks, and experimental environments. 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 identify a robot's function. The participants in the previous study knew how to make the robot function. If knowledge of the robot's function is taken into consideration, we think that motion feedback would be the most effective way of assisting humans to interact with it because they would know the robot's functions, and sound would help them when they did not.

Additionally, we consider that *partial execution* is one of the best strategies to implement Action Sloping. The feature of partial execution is that a modality of feedback behavior is identical to that of a function. When a user knows the target function and tries to find the triggering action for it, they will easily estimate the whole target function by seeing a feedback by partial execution. Although participants in our experiments did not know target function, the motion feedback executes part of the robot function.

4.2 Experimental Task

In our experiment, we used touch duration as continuous-valued signal to capture user actions. To apply Action Sloping, a designer generally defines user actions as horizontal axis in by converting them into continuous or ranked values, and decides feedback intensities to each action. For instance, touch duration, distance, and speed are easy to use. If a robot has multiple functions and each function is assigned to a sensor, a designer can follow the procedure mentioned above. However, if multiple functions are assigned to a sensor, it is difficult to apply Action Sloping because there is a risk that a user might confuse some robot functions by observing disorganized feedback signals. The development of design method for such situation remains to be solved.

The experimental task was similar to playing with the robot because we instructed participants to identify the robot's function. Such a task is suited to a robot that has the ability to help users and to play with them. Users will not try to identify robot's unknown functions while the robot is operating. However, making the task seem like play improve the sociability of robots and makes situations similar to this one.

The problem with these experiments was that the robot had only one 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 conduct experiments using a robot with multiple functions. In our future study, we will use a robot with multiple functions and provide a function list to users before experiments. We consider that *partial execution* is useful for users to execute a function, because they can easily predict robot's future behavior by observing its feedback signals. The experiments include controlling participants' motivation by telling them that they will receive extra compensation for each action.

In addition, it is important to investigate the relationship between a function modality and feedback modality through a combination of auditory, visual, motion, and non-feedback. The design of experiments takes four-by-four combinations. We will also attack these experiments to demonstrate the availability of Action Sloping.

4.3 Influence of robot's appearance, task and users' personalities

We need to discuss various properties of a robot, users and relationship between them. Task structure [22] like cooperative/competitive properties has influences into Action Sloping. In our work, since users just tried to find a robot's function, there was little cooperation between the users and a robot. However, in a practical situation, users have a cooperative/competitive task with a robot, and function awareness becomes a sub-task for the task.

We consider that robot's appearance has significant influence into Action Sloping. Users inevitably build a model from the appearance when they face a robot, and act according to the model [7]. In our study, since the robot had appearance like a dog, users deal with the robot in the same way to a real dog (e.g. users tend to stroke a dog's head as positive reward [6]). We did not utilize such a dog-like model to facilitate function awareness. However, it is a promising way to use Action Sloping for selecting a triggering action.

Another property influencing to effect of Action Sloping is users' personal traits. We consider one of the most influent personal traits to Action Sloping is users' experience to keep a dog [8]. We expect users who have kept a dog act in the different way to a robot from users without such experience. To investigate the influence is our open problem.

Nomura et. al investigated influence of users' negative attitudes toward a robot [10]. They observed participants' behaviors to a robot and reported the result that women feel more familiarity to the robot than men do and their experiences of real robots influence the relations between negative attitudes and behavior for robots. In our study, we did not deal with such personal difference. These influences for Action Sloping have been left uninvestigated here for future work.

5. Conclusion

When robots have multiple functions, users will have to read thick operation manuals before they can use them. If users can use robots without reading the manuals, it will improve their efficiency. We propose Action Sloping which is gradual change in feedback behavior as the user performs actions, as a way for users to learn about a robot's functions. Changing the intensity of the feedback behavior in response to the user's actions encourages them to take actions that trigger the robot's function. In the experiments, we equipped a robot dog with three patterns of feedback behavior based on the Action Sloping concept and one non-feedback behavior as the control condition. The participants tried to identify the robot's function, and the latency times for identifying the triggering action were measured. An analysis of the latency times showed that only participants in the chirping sound condition were significantly faster in identifying the triggering action than the non-feedback condition participants. We then conducted an additional experiment to investigate the major factors in the effect of the chirping sound and used a sound with constant frequency as feedback, which is not in accord with the Action Sloping concept. The results showed that changing the pitch of the sound significantly encouraged the participants to touch the robot's head for a long time. The effectiveness of Action Sloping was partially supported, and we obtained knowledge that will help in designing home robots.

Acknowledgment

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Biography

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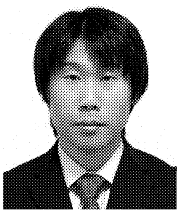

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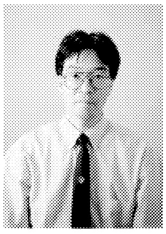

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