Action Sloping for Manual Free Robot

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***Abstract*— In this paper, we deal with the problem that will arise in the near future from robots with a lot of functions. The problem is that the robot users will have to read thick operation manuals. We designed an interaction that allows users to easily notice a robot's function without reading the manuals. We define Function Awareness as "to notice the relationship between a user's action and a robot's action." We propose a guideline for designing robot's actions as, "Action Sloping," which allows a robot to gradually express its internal state and also allows the user to naturally notice the robot's function by observing its actions. We designed the concrete robot's actions for a sweeping robot, and the robot changes the velocity of its motion to indicate its internal state according to the distance between the robot and its user. We develop a robot that can perform Action Sloping using low-cost infrared sensors and simple rules for actions. Through experiments, we investigated the users' behavior and clarify the problems with the proposed method.**

I. INTRODUCTION

Recently, there has been an increase in research focusing on home robots [1]. For example, an autonomous lawn mower, Robomow[1] and an autonomous sweeping robot, Roomba[2], have been developed for practical use. It is anticipated that such home robots will become increasingly sophisticated and have multiple functions like conventional home electric appliances. However, this will cause a usability problem. A robot with multiple functions can easily confuse its user because they cannot comprehend all its functions. The user will also have difficulties in reading its thick operation manuals upon introduction to them. Such problems are typically found in the latest mobile-phones with multiple functions.

Therefore, we propose an interaction design for complicated robots. It allows a user to become naturally aware of a robot's function. We call a user's awareness of the relationship between the user's actions and robot's actions as, *Function Awareness*. To achieve Function Awareness, we employ an approach that helps the user become aware of a robot's function through expression of its internal state. There has been some research into human robot interaction; however, there is no research into Function Awareness. Ono et al. [2] have developed a technique for understanding a robot's internal state by improving the user's familiarity with the robot. Komatsu [3] has reported that users can infer a machine's internal state from its beeps. Although these researches deal with a machine's internal state, they do not mention a way for a user to notice its functions. The Theory of Mind [4] also relates to our study, but it is difficult to apply the theory to the problem with complicated robots.

In this study we employ a nonverbal way for a robot to express its internal state because it provides independency of a specific language and low cost implementations. Some researches have shown that nonverbal communication provides rich information. Watanabe et al. [5] have argued on the importance of nonverbal information in the form of head movements, such as nodding, in communications in their virtual space. Matsumaru et al. [6] have shown that their mobile robot expresses its direction of movement by a laser pointer or an animated eye. Nonverbal information is an essential factor for human-robot social interaction [7] and the instruction methods in which a robot observes human actions [8][9]. Therefore, we believe that nonverbal methods are preferable because of their rich information, simplicity, and no need for additional equipment. In a nonverbal way we can employ a lot of methods, such as LED flushing or beep sounds. We employ a robot's movement because Kobayashi et. al [10] have shown that the robot's movement encourages the user to perform a collaborative action in comparison with the LED flushing and beep sounds.

The important things to consider for achieving the Function Awareness are how a robot can make a user easily understand its internal state and the performance of a particular action relating to its function. In this paper, we propose *Action Sloping*, which is where a robot expresses its internal state gradually according to the user's posture. The rest of this paper is organized as follows. In Section II we give an overview of Action Sloping. In Section III our experiments and results are presented. We discuss the effects of Action Sloping in Section IV. Finally, we make a brief concluding remark and introduce future work in Section V.

II. ACTION SLOPING

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

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

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

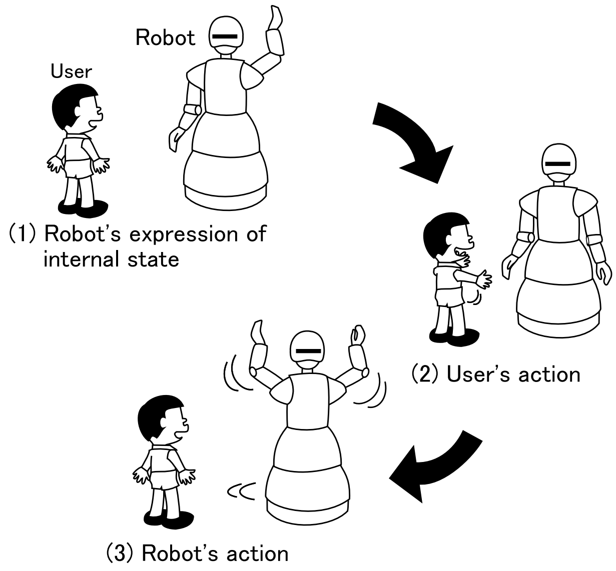


Fig. 1. Function Awareness

for the desired functions and studying how to operate it are complicated tasks for the user. Therefore, it is better for the user to comprehend its functions without reading the manuals.

The following three step interaction assists a user in understanding a robot's function without reading its manuals (Fig.1).

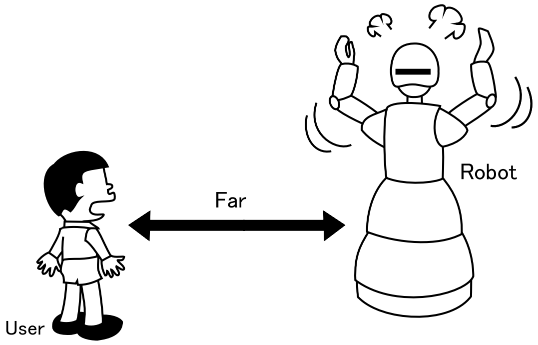
1) *Expressing the robot's internal state:*
   the robot expresses its internal state and has the user take some sort of action.
2) *Taking a user's action:*
   the user understands the robot's internal state, and then takes an appropriate action accordingly.
3) *Performance of a robot's function:*
   the robot performs a function corresponding to the user's action.

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

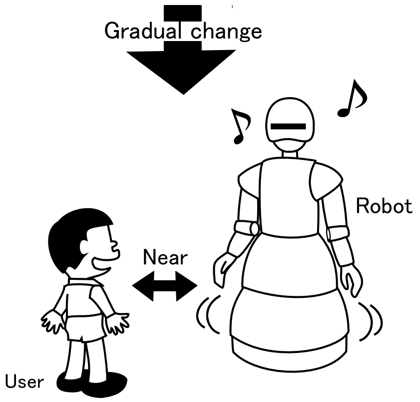
B. Action Sloping for achieving Function Awareness

The key technology for achieving Function Awareness is how a robot helps a user easily understand its internal state and perform a particular action to trigger a function. Therefore, we propose *Action Sloping*, which is the way for a robot to express its internal state according to a user's posture. The robot can gradually express a positive or negative internal state by applying Action Sloping. When the user makes an action connecting to a specific robot's function, the robot expresses a positive state as feedback. In contrast, when the user makes an action connecting to none of the robot's functions, the robot expresses a negative state.

For example, image 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 expresses a negative state when the user places something like a washed dish to far from a designated point, and expresses a positive state when the user places it near a designated point (Fig.2). The robot gradually expresses its state from negative to positive. Once the user observes these gradual attitude changes, he/she can place the dish closer to the robot. Such action would cause the robot to put it away. Therefore, the user can perform an appropriate action without reading the robot's manual. Figure 3 shows the typical interaction we assume.



(a) Robot's negative expression



(b) Robot's positive expression

Fig. 2. An example of Action Sloping

user: place an object in front of the robot
robot: perform negative expression
user: place it near to the robot
robot: perform positive expression
user: place it nearer to the robot
robot: perform positive expression
user: place it nearer to the robot
robot: take it and then put it away (perform function)

Fig. 3. Typical interaction by Action Sloping

C. Model of Action Sloping

Figure 4 shows a model for Action Sloping. The horizontal axis represents a user's actions, and the vertical axis represents a user's awareness of a robot's function. In the conventional way, represented by the dotted line, a user can notice a robot's

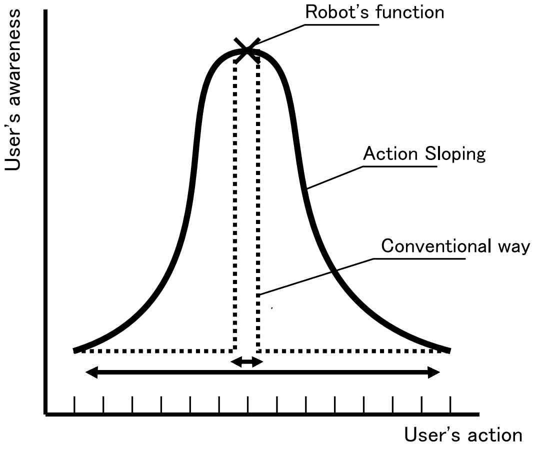


Fig. 4. Action Sloping Model

function when he/she makes an action connected to a function (on the center of the horizontal axis), and he/she cannot notice the function by performing another action (the horizontal part of the line) because no feedback occurs. On the other hand, the proposed way, represented by the solid line, can provide gradual feedback according to the user's actions. The line takes the form of a slope and, therefore, Action Sloping allows the user to easily notice the function.

D. Designing Robot Behavior

We have developed a design method for producing concrete robot's feedback motions according to Action Sloping. The motions have a strong dependence on its hardware and tasks. We focused on some common factors for designing a robot. Two of them are to express comprehensible positive/negative state and to change the motion gradually but clearly from negative to positive. In this paper, we employ speed of motion for expressing its state. The fast motion represents a negative state and a slow motion represents a negative one. The fast motion can express failure. The user will get a negative impression from a failure motion and a positive impression from a normal one.

The other important design factor is how to assign a gradual motion to the user's action. This factor strongly depends on the robot's sensors. The sensor we focus on is an infrared sensor. It can obtain the distance between a human body and a robot's body. It is a cheap sensor and easily obtainable. The robot we assumed performs a specific function when it senses something at a certain distance by using infrared sensors. Its state, expressed by fast/slow motions, is assign to the distance between them, such as in Fig. 2.

Therefore, we can design a robot to express its internal state by changing its motion speed according to the distance between the user and the robot. This method encourages the user to perform an action that triggers a robot's function.

III. EXPERIMENTS

We performed exploratory experiments to evaluate the effect of Action Sloping. First, we applied Action Sloping to a small mobile robot on a sweeping task. Next, we investigated users' reactions to the sweeping robot.

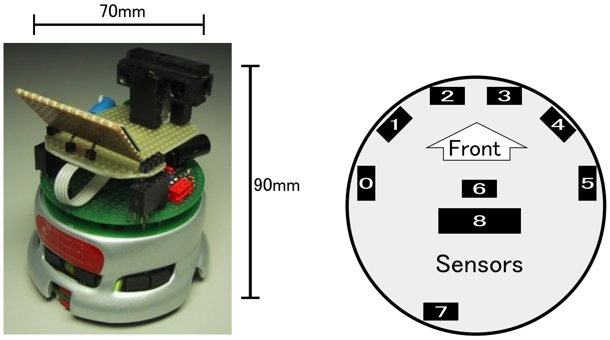


Fig. 5. KheperaII

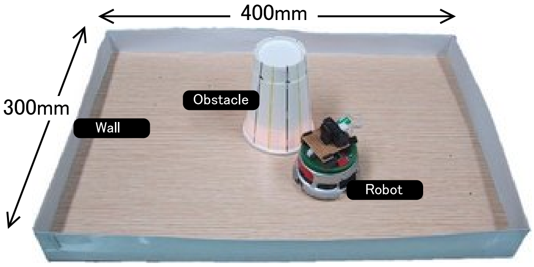


Fig. 6. Experimental environment

A. Robot and Environment

We used a small mobile robot, KheperaII (Fig.5). The robot has eight infrared proximity and ambient light sensors with up to a 100 mm range, a Motorola 68331 (25MHz) processor, 512 Kbytes of RAM, 512 Kbytes of flash ROM, and two DC brushed servo motors with incremental encoders. Its program, written in C-language, runs on the RAM. We rearranged an infrared sensor and added an infrared sensor with up to an 800 mm range (SHARP GP2D12) for sensing its overhead.

Figure 6 shows the experimental environment, which had a flat surface (400 mm × 300 mm), a wall surrounding it, and an obstacle. It simulated an ordinary human work space like a desktop. The obstacle corresponded to a pen-holder, remote control, etc., and could easily be moved by a participant. It had an electric light bulb so that the robot could distinguish it from the wall.

B. Behavior of robot

The robot autonomously swept the floor in the environment. It performed random turns in front of the wall. It was unable to clean the floor because it was difficult to implement air aspiration equipment on the small robot. It moved along the side of the obstacle to encourage the user to move it. When the user moved the obstacle, the robot stopped and expressed its internal state by using Action Sloping. It expressed its internal state by spinning itself. Figure 7 shows a robot's expression by a change in its spinning speed according to the distance

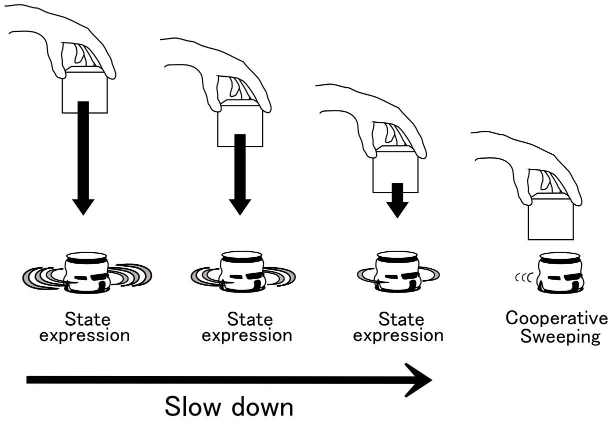


Fig. 7. State expression by using Action Sloping

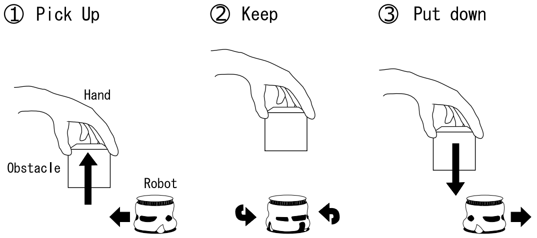


Fig. 8. Cooperative Sweeping

between the obstacle and the sensor on its top. When it sensed an object close to its top, it spun slowly. When it sensed the object far from its top, it spun fast. The spinning expression was performed when the object was placed within a distance of 20 to 800 mm.

The robot had a specific function. We called it *Cooperative Sweeping* [11]. Cooperative Sweeping was performed when the user placed the obstacle near its top with a range from 5 to 20 mm. This function enabled the robot to sweep the floor under the obstacle by priority taking while the user held it. Figure 8 shows this Cooperative Sweeping. It repeated spinning and going straight under it, and finished Cooperative Sweeping when the user put the obstacle closer to its top with a range from 0 to 5 mm and then went elsewhere.

C. Implementation of robot's behavior

We employed subsumption architecture [12] for the behavior-based approach. Figure 9 shows the three-layered architecture used for the robot. Each layer asynchronously checks the applicability of behavior and executes it. The higher layers suppress the lower layer's, and the lower layers have more reactive behavior. The behavior of each layer consisted of multiple actions. When the system simultaneously obtained multiple outputs, it generally selected the highest layer's action. Each layer had a frequency for action output to smoothly control the robot. We set 5 msec intervals for the 1st layer, 10 msec for the 2nd layer, and 5 msec for the 3rd layer. Obstacle avoidance and interaction occurred most frequently. The 3rd layer included the state expression by using Action Sloping and Cooperative Sweeping.

Layer 1: Obstacle Avoidance
- Stop if something is sensed in front of the robot and it is going forward.
- Stop if something is sensed behind the robot and it is backing up.

Layer 2: Random Sweeping and Wall Following
- Move forward if the robot senses nothing in front of it.
- Follow the lit object clockwise if it senses the object on its left.
- Follow the lit object counterclockwise if it senses the object on its right.
- Turn clockwise in a range from 90° to 180° if something is sensed on its right.
- Turn counterclockwise in a range from 90° to 180° if something is sensed on its left.

Layer 3: Interaction
- Expressing a state if a lit object is moved and the robot is moving along the side of it.
- Go straight if something is sensed above the robot's top and it is expressing a state.
- Go back and turn clockwise in a range from 90° to 180° if something above the robot's top is removed.
- Go straight if something is placed close to the robot's top.

Fig. 9. Subsumption architecture of robot

Figure 10 shows snapshots of actual robot's behavior. When the obstacle was placed at more than 220 mm from the top of the robot (4th), it performed the fastest turn (about a 360° roll per second). When the obstacle was placed the nearest (20 mm from its top) (6th), it performed the slowest turn (about a 360° roll per 5 seconds).

D. Method

The purpose of the experiment was to investigate participants' reactions to the sweeping robot and to evaluate the effect of Action Sloping. We explained to the participants that the machine was a sweeping robot, it repeated spinning in front of a wall, and imagined its path was cleaned, because it could not perform dust collection. In addition, we asked them to help it if necessary.

At the beginning of the experiment, the robot started autonomous sweeping and then followed the object. The robot begun to express its internal state when the participant moved the object. If the participants did something for it, it changed the spin speed or performed the Cooperative Sweeping.

We prepared two robot's state expressions and three additional explanations. Figure 11 shows the details of the expressions and the explanations.

E. Results

Four females and three males in their 20's to 30's were the participants for these experiments. Table I shows the experimental results. In the figure, "No." is the participants' ID, and "State" and "Explanation" are the ways for the robot's state expression and the additional explanation, respectively,

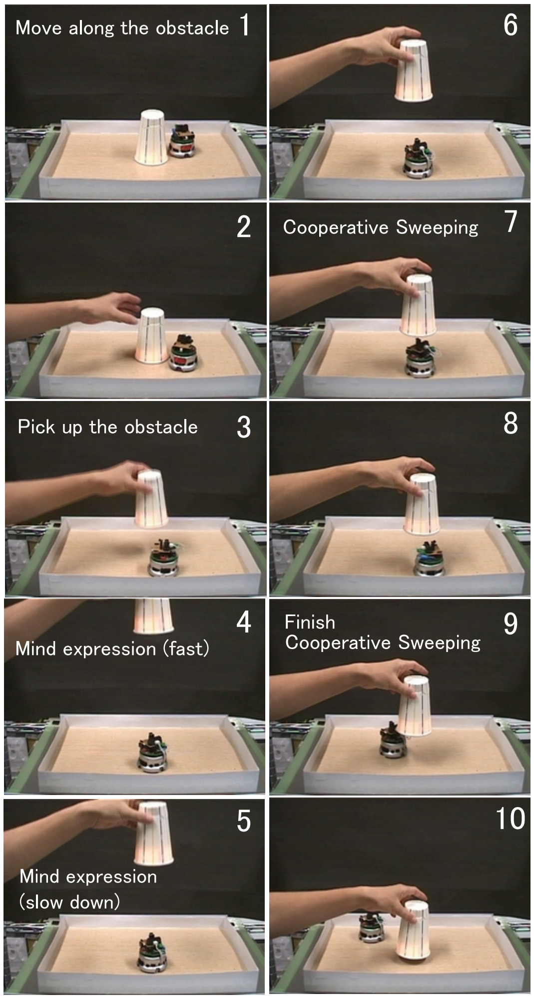


Fig. 10. Snapshots of robot's behavior

State expressions:
S1: A negative expression is represented by a fast spin; a positive expression is a slow spin.
S2: A negative expression is represented by a stop and a slow spin; the positive expression is a fast spin.

Explanations:
E1: Do not move the robot.
E2: The robot does not easily get broken.
E3: The robot can sense over its head.

Fig. 11. Details of state expressions and explanations

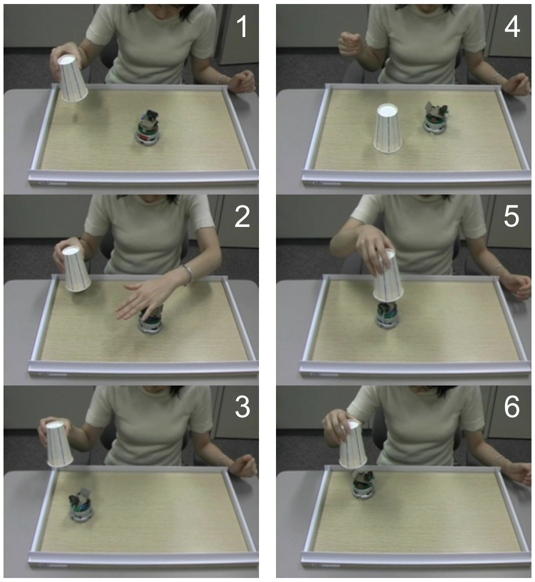


Fig. 12. Snapshots of participant's behavior

outlined in Fig. 11. It shows whether a participant moved the obstacle (MoveObj), placed it on the robot's top (TopObj), and noticed the robot's function, Cooperative Sweeping (Aware). Figure 12 shows participant's behavior.

According to Table I, there was no participant who noticed the function. However, all participants moved the object and a few participants placed it on the robot's top when we explained to them that it could sense something over it. The actions performed by the participants will provide helpful information for the development of Action Sloping.

We did not conduct officially Kansei evaluations in the experiments. However, we obtained several comments from the participants. Some participants felt the robot getting broken when it performed the fast spin. Others felt it careful cleaning.

IV. DISCUSSION

A. Participants' reaction

In the experiments, there was no participant who noticed the Cooperative Sweeping function. We have taken into consideration that this result would be caused by the timing of the robot's state expression. Users often use machines with a clear purpose; however, the participants seemed to have no consciousness of their purpose of action. They just reacted to the robot without thinking of how efficient it was. We then took into consideration that the timing is important for users to perform something associated with their working efficiency.

In the experiments we explained to most of them that the robot did not break down easily (E2). We added this explanation because one participant thought the robot break down and she fled the room when we explained E1. However, explanation E2 is not preferable for a manual free machine. An interaction design using a failure expression may have the disadvantage of making a user nervous.

In the case of explaining to them that the robot could sense objects above it (E3), two out of three participants placed the object above the robot. This explanation is also not preferable. We can deal with this problem by visualizing a sensor on it. For example, attaching an eye-like picture near a sensor or having the robot behave autonomously according to the output of the sensor on its top. The participants without E3 explanation moved the object to the robot's sides. We took into consideration that their actions were a result of observing

TABLE I

EXPERIMENTAL RESULTS

No.	State	Explanation	MoveObj	TopObj	Aware
1	S1		Yes	No	No
2	S1	E1	Yes	No	No
3	S1	E1,E2	Yes	No	No
4	S1	E1,E2	Yes	No	No
5	S1	E1,E2,E3	Yes	Yes	No
6	S2	E1,E2,E3	Yes	No	No
7	S2	E1,E2,E3	Yes	Yes	No

its autonomous behavior, spinning in front of obstacles. If we make the robot behave autonomously according to the output of the sensor on its top, users will notice the sensor without explanation. The most important problem throughout the experiments was that the participants were unable to notice the Cooperative Sweeping function. The function would originally be difficult to notice. It would also be difficult for them to conceive of holding the object above the robot. We observed that most of the participants moved the object horizontally, but they did not move it vertically. Therefore, better results could be achieved with robot design that gives a demonstration of a vertical movement according to the output of the top sensor.

In the exploratory experiments we made the robot express both positive and negative states to encourage its user to do something. This was just an illustrative case. We are now planning different experiments with a different robot and a different method of expression. We will compare the efficiency of the robot with the Actions Sloping and without it by observing the users' behavior.

B. Limitation of Action Sloping

In the experiments the robot had only one function, Cooperative Sweeping. The manual free machine solves the problem in a situation where a user cannot naturally and intuitively use a robot due to the multitude of functions it has. We are also planning an experiment with a robot that has multiple functions. The implementation is heavily dependent on its hardware. Therefore, we will employ an AIBO instead of a KheperaII, because an AIBO has a lot of actuators for performing functions and expressing its state, and many types of sensors for collecting the user's actions. In our experiments we employed distance as a cue to control the robot; however, a user's touch and voice will be available for the Action Sloping in the next experiment.

In the present state of action sloping, we assume that a robot has a single function. Thus we can carefully design a single action sloping to the robot's function. However, if a robot has several functions, it will be quite difficult to design action sloping for each function because action sloping may interfere together.

V. CONCLUSION

We dealt with the problem that will arise in the near future from robots with a lot of functions. The problem will be that a user will have to read their thick operation manuals. Then, we designed an interaction where users can easily notice a robot's function without reading the manuals. We propose "Function Awareness", which is defined as, "to notice the relationship between a user's action and a robot's action." We also proposed a guideline for designing the robot's actions called "Action Sloping," which has a robot gradually express its internal state and encourages a user to naturally notice a robot's function by observing its actions. We designed concrete robot actions for a sweeping robot, and the robot changed the velocity of its motion to indicate its internal state according to the distance between the robot and its user. We developed a robot performing Action Sloping that used low-cost infrared sensors and simple rules for actions. In experiments, we investigated the users' reactions for the robot and clarified some problems. We are now planning different experiments with a different robot and a different method of expression to confirm the effectiveness of Action Sloping.

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