Investigation of Object-indicating Behaviors
Between Spacial Difficulty and Robot's Degree of Freedom

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Abstract: In this paper, we introduce an expressive method of the robot's "*effort*" and "*hardships*" while indicating a particular object. For the popular designs of robots which have few degree of freedom, it should be very important to design delicate but effective behaviors to express additional effort to solve the difficulty. Accordingly, we propose adopting additional and delicate motion of the robot's head in addition to pointing gesture by the robot's arm. The results of our preliminary experiments with subjective and objective experiments showed a) the difference of the object sensation by age, b) the strength of the arm for the object indication, and c) the possibility of robot's expression for "*effort*" using the additional motion of the robot's face toward left side, differently from the direction of the arm. Finally, we suggest an geometric model of difficulty and the gradual expression of effort corresponding to the difficulty.

1 Introduction

The progress of the aging society in recent years causes serious problems on nursing cares for elderly people and dementia patients. Due to costs, and shortage of human resources, it is impossible to watch and care these people and patients every minute. To solve these problems, many researches are aiming to introduce robots or agents to such scenes and to create environments where the patients are always watched by the robots and virtual agents [1, 2, etc.].

When human communicate with others, situations and objects around them become common contexts. During the communication, they need to indicate objects concretely by using both verbal and non-verbal information to share common awareness.

However, when the robot want to point at the target located behind the user by using nonverbal expressions, it is difficult to indicate the referent by only the pointing gestures. To realize appropriate pointing gestures, the robot should consider not only relative positional relations between the robot and the user but also user's situations such as easiness of paying attention to surrounding environment. In addition, when the user do not recognize difficulties of indication that the robot want to point at, the user can be easily misunderstood instructions. This is problematic situation because the user do not notice that she/he misunderstands the robot's pointings.

Thus, in this research, we examine the difficulties of the pointing depending on the relations among the pointing targets and users and propose a behavioral design of the pointing gestures that is suited for the agent.

We have been doing researches about information providing by the robots and virtual agents depending on user's context and situations [3, 4]. These researches show the importance of understanding user's context. But we have not been discussed about the difficulties of delivering "pointing" information when the user and the robot want to understand each other.

Kindness and patient effort by the robot is important for the users and the user's feelings, especially for elderly people, dementia patients and children. We've also been done research about difficulties of conveying information to the user [5]. In the research, the robot changes their behaviors whether the robot is easy to talk to the user or not for appropriate communications. Trying to communicate carefully allows us to deliver the pointing information. Furthermore, robot's behaviors for overcoming the difficulty of instruction may let the users feel the robot's humanity. and the user may have attachment to the robot.

In this paper, we consider about the situations when the robot and the user share the common object from the multiple choices, and analyse the differences of the interpretation of the robot's pointing gestures by age, sex, and behaviors for the pointing gesture itself.

2 Related Researches

Pointing gestures are important as nonverbal behaviors [6] in human-human communications and human-agent/robot communications as same as gaze behaviors [7], since these behaviors can be a trigger for joint attention. Indication of particular objects between human and artificial agents are very related to our mental space for common understandings as same as gaze behaviors [8]. Thus, many researches on pointing gestures for anthropomorphic presences have been done so far [9]–[15], etc.

Some researchers have implemented and investigated about pointing gestures performed by the robots [9]–[11] and agents [12]. In these researches, the effects of combining verbal indication (demonstratives) and nonverbal indication (pointing gestures) are analyzed. However, difficulties of pointing only by nonverbal information are not mentioned.

On the other hand, in various human-human communication situations, accuracy of detecting referents by pointing gestures have been measured [13]–[15]. According to these researches, not only pointing gestures but also gaze information are important for estimating referents of others accurately,

Many agents and robots do not have enough degree-of-freedom(DoF) to express accurate pointing gestures and gazing direction. Especially, since stuffed-toy-robots have no DoF for gazing behaviors, they need to express the gazing direction as their head directions, and difficulties to estimate the referent targets are further increased.

Therefore, in this paper, we investigate a design of pointing gestures that are easy to estimate the referent targets accurately for agents and robots that have limited DoFs.

3 Tentative Expression and Evaluations of Indication Difficulty

3.1 Gestures of Additional Effort

It is necessary to recognize and indicate a particular object by a robot when the user and the robot have communication related to a common object in real world. The pointing or indicating situations have each different difficulty. If the difficulty of the indication were expressed by the number of the interactions, the user should be tired in the communication. Accordingly, we focused on the expression of *difficulty* and *effort* to indicate a correct object.

When the object is far from the other person, or when the object is difficult to be found by the other person, people sometimes show their efforts to indicate the object with inclining their bodies or heads, or crane their necks. On the other hand, the degree of freedom in popular robots are limited compared to the human motion. We focused on the head motion of robots because almost all of robots have kinetic implementation of the head motions at least two degree of freedom. The target of the difficulty in this paper is a backward object for the user. We propose to adopt a gesture of"nod toward the object" to the robot.

In Figure 1, the pattern A shows normal pointing gesture using the hand (without a delicate motion of the head). The pattern B shows "nod toward the object" with a delicate motion of the head. The pattern C shows our concept: a basic indication using the hand with a delicate motion of the head of the robot to show the robot's additional effort for the difficulty.

Our proposed behavior of the difficult indication is as follows. The robot moves its arm to the object. It also moves its head to upward or left side about 10 [deg.] in 0.5 seconds while it keeps its arm indicating the object. Then it moves its head toward the user in 0.5 seconds. Finally, the robot stop pointing the object out.

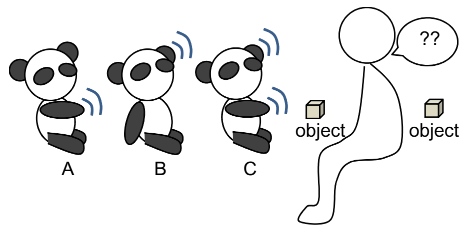

Figure 1: Expressions of indication difficulty

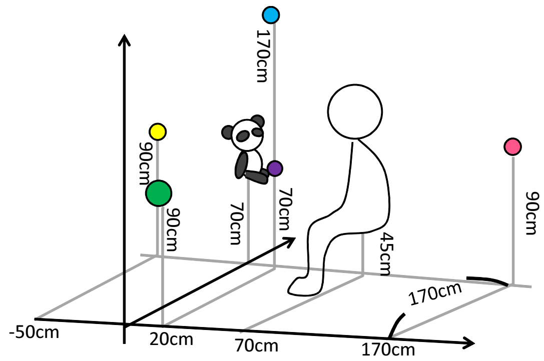

Figure 2: Experimental settings

3.2 Preliminary Experiment

In order to investigate the difficulty of object indication by a robot, we conducted a dialogic experiment. It is possible that the participants differently recognize the indicated object by their generations or genders. To clarify the difficulty of the indication and the recognition of the participants by various behaviors of the robot, multiple color balls were placed around the participant to observe discrimination and recognition of the backward object.

Hypotheses: I) The robot's actions using directions of its a) arm and b) face differently indicate a particular object to the user. II) The combination of the robot's a) arm and b) face can point out a particular object even in the difficult place to indicate.

Participants: Twenty-six people (thirteen females and thirteen males) aged from nineteen to twenty-five participated in the experiment as "young" subject group. Twenty-six people (thirteen females and thirteen males) aged from sixty-four to seventy-five participated in the experiment as "elderly" subject group. These participants had normal color vision.

Experimental settings: We used a stuffed-toy robot [16] covered with a panda-like stuffed-toy, and set five color balls at various places to distinguish the indicated ball. Figure 2 shows the setting of the experiment and Figure 3 shows the experimental view. The five balls were settled at each coordination as Figure 2. A pink ball was set at the backward of the participant. A purple ball was set between the user and the robot (in front of the robot). A green ball was at the left side of the participant, differently from the other balls. A blue ball was settled above the purple ball.

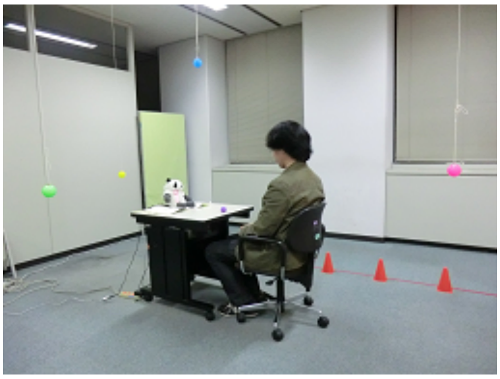

Figure 3: Experimental view

A yellow ball was set behind the robot.

The robot moved its hand about 90 [deg.] forward (`forward(arm)`) or left (`left(arm)`) and kept the pose for three seconds. The robot also moved its face about 10 [deg.] upward (`f(u)`) or left (`f(l)`) for one second at the same time.

Conditions: In each condition, the robot asked the color of the ball with two types of behaviors. In the condition `h`(hand), the robot moves only its left hand to indicate a particular object. The condition includes `left(arm)` and `forward(arm)`. In the condition `f`(face), the robot moves only its head to indicate a particular object. The condition includes `f(l)` and `f(u)`. In the condition `h+fl`, the robot moves its right hand and head (toward left direction for the participant) to indicate a particular object. The condition includes `left(arm)` and `forward(arm)` with simultaneous `f(l)`. In the condition `h+fu`, the robot moves its right hand and head (toward upside) to indicate a particular object. The condition include `left(arm)` and `forward(arm)` with simultaneous `f(u)`.

Procedures: At first, the participant confirmed the colors of the balls around her/his chair before the experiment. The experimenter allowed the participant to look at any ball to confirm the colors during the experiment.

The participants were instructed to reply only one color to each question of the robot. The robot asked "What color is the ball?" to the participants with various behaviors. There was two questions in each manner in one condition. The interval between the first and second question was about six seconds. After the experiment in one condition, the participant e The conditions were counterbalanced.

Statements for subjective evaluations: In each condition of the experiments, the participants evaluated each stimulus using a five-point rating scale on relevance (5: very relevant, 4: somewhat relevant, 3: even, 2: somewhat irrelevant, 1: irrelevant) of the statements as follows.

`[atti]`: The attitude of the robot was preferable.

`[effo]`: The robot seemed to make effort for explanation.

`[comp]`: The question from the robot was comprehensive.

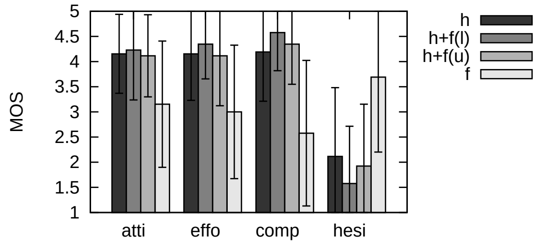

Figure 6: Subjective evaluations (elderly)

`[hesi]`: It was difficult to identify the ball.

Results of participants' answers: Figure 4 and 5 shows the summaries of the participants' answers to the robot's question in each conditon. The figures are summarized results by each questions; same behaviors of the robot's face are shown in the same row, and same behaviors of the robot's arm are shown in the same column. The condition `h` had two questions as shown in A and B in the figures. Two questions in the condition `h+fl` are sumarized in D and E. The results in the condition `h+fu` are shown in G and H, and the results in the condition `f` are shown in C and F.

As can be seen in two figures, there were different data-spread between elderly and young people. Especially in the center column, indicating the pink ball backward of the participant, many elderly people answered "purple." It is conjectured that the accurate direction of the object is difficult to be recognized by elderly people.

Next we focus on the difference of the direction of the robot's arm. Each column showes different tendencies and we could verify a strong effect of the pointing gestures by the robot's arm. When the robot points at the pink ball, some of the participants could not pay attention to the pink ball because of the field of view although the pointing angle was indicating at the pink ball.

The difference of the facing behavior showed interesting possibilities. The condition `f` as shown in the left column showed the scattered results by facing at the left side (`f(l)`). On the other hand, the number of the answer "blue" was increaced when the robot moved its face upward (`f(u)`). It is conjectured that the face motion in 10 [deg.] cannot indicate a particular object. We assume the results were affected by the accuracy of the indicating angles.

When we observe the results of the combination of its face and arm pointing the pink ball (A, D, and G), `f(l)` showed the best result in the elderly people. In the young people, pointing by only the robot's arm was the best, however, `f(l)` showed better result than `f(u)`.

Results of subjective evaluations: Figure 6 and 7 show the results of the subjective evaluations by each age groups. Table 1 shows ANOVA results by three factors: age, gender (between subjects), and conditions (within subjects). The gender factor and interactions did not show any significance. On the

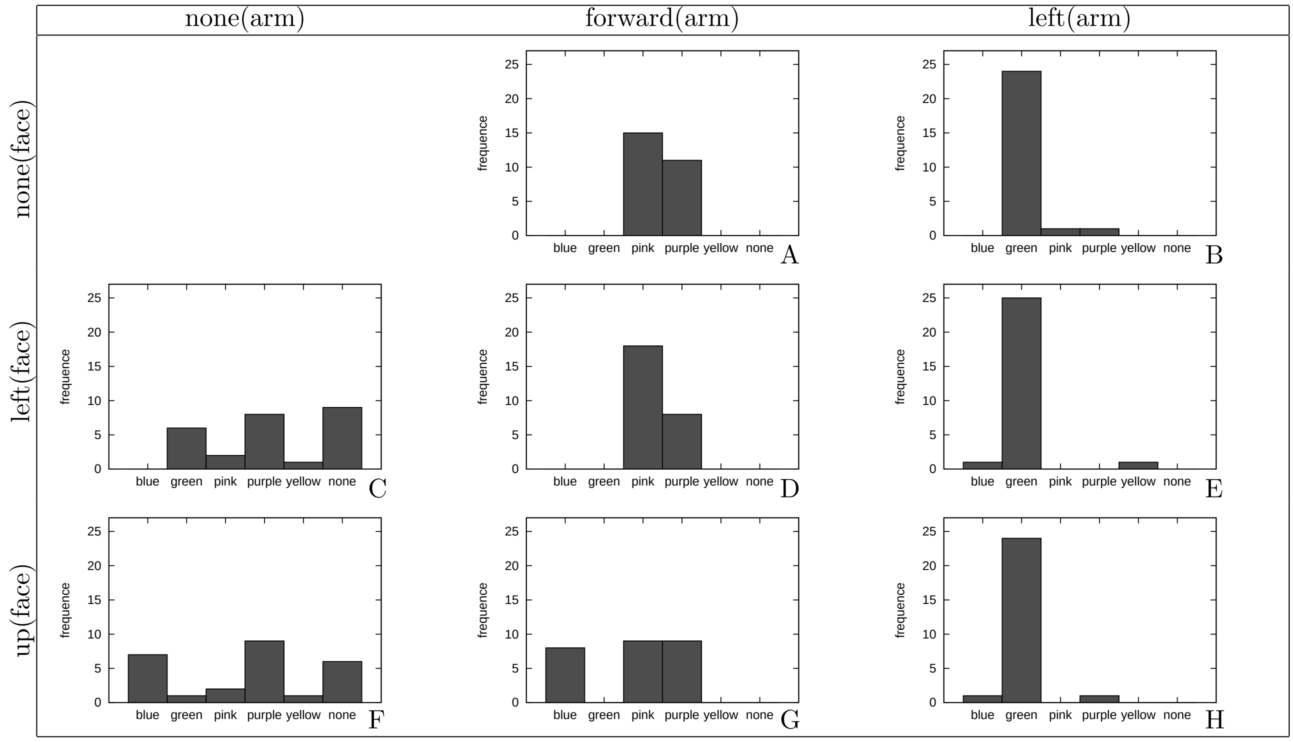

Figure 4: Frequences of presumed balls (elderly)

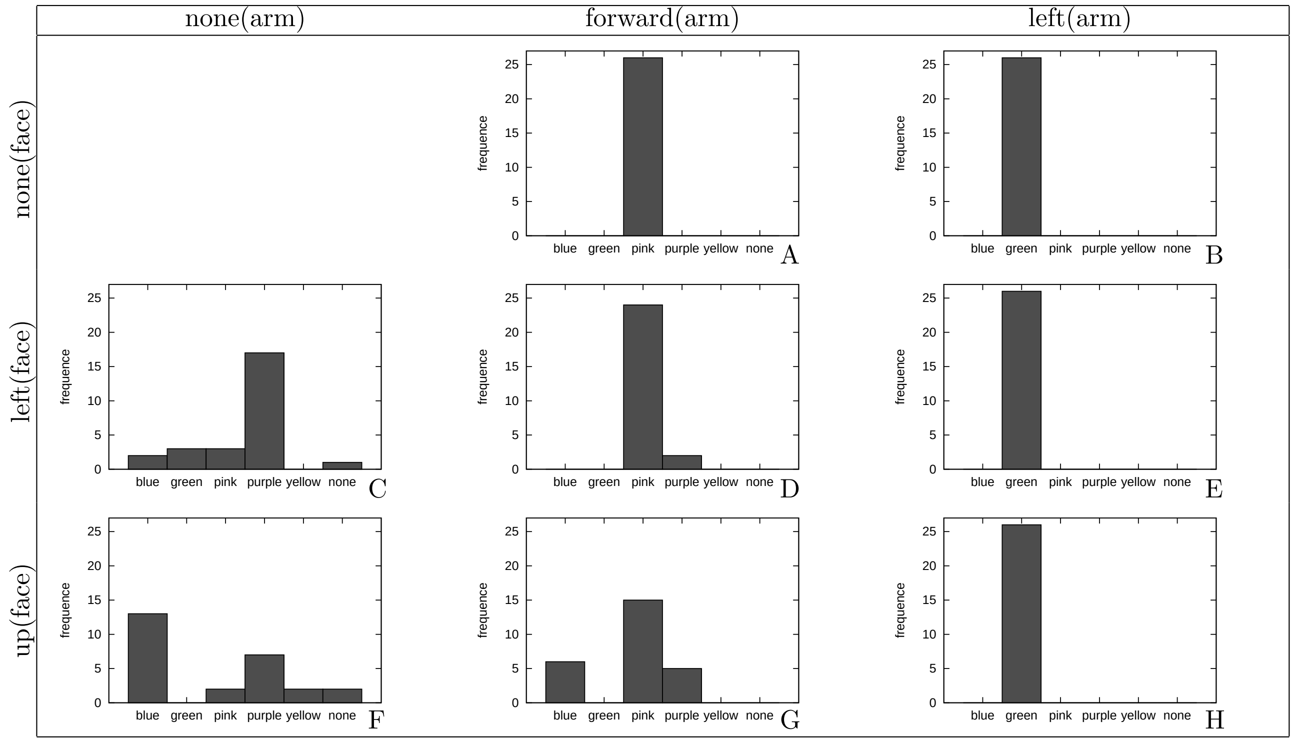

Figure 5: Frequences of presumed balls (elderly)

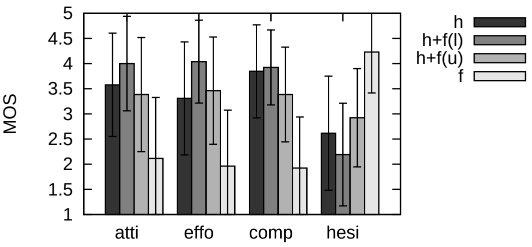

Figure 7: Subjective evaluations (young)

Table 1: ANOVA results for subjective evaluations

		gend.	age	*cond.*	post-hoc
`atti`	F	.002	8.79	34.4	`f` – others
	p	.965	.005	<.001	
`effo`	F	.081	12.3	39.8	`f` – others,
	p	.777	.001	<.001	`h`–`h+f(l)`
`comp`	F	.00	12.5	61.8	`f` – others
	p	1.00	<.001	<.001	
`hesi`	F	1.55	16.8	31.1	`f` – others
	p	.218	<.001	<.001	

other hand, the age factor showed significance in all statements. The elderly people totally scored higher than young people. We also observed many elderly participants felt affection to the robot after the experiment.

The significant results by the condition factor were found in all statements. The post-hoc tests using Turkey-Kramer with significant level 0.05 showed significant results between `f` and other conditions in all the statements. We assume that the indication only by its face upward was recognized as impolite "*nod past*" behavior, differently from the face motion to the left side. Additionaly, the results of the `effo` statement showed significance between `h` and `h+fl`. It is conjectured that the effort of the robot was recognized by the face motion to the left side compared to the pointing gesture only by its arm.

Summary of Results: The difference between the elderly and young people show some possibility of the different level of attention to the user's backward. The elderly people felt the backward object when the robot pointed the direction of the pink ball with moving its face to the left side. In the subjective evaluations, the face direction to upward was regarded as undesirable behavior. The significance was found between `h` and `h+fl`. From these results, we assume that the pointing gesture using the robot's arm with its face motion to the left side was effective to indicate an object at the backward of the user, especially for the elderly people. Thus Hypothesis I) was confirmed and Hypothesis II) was partially conjectured.

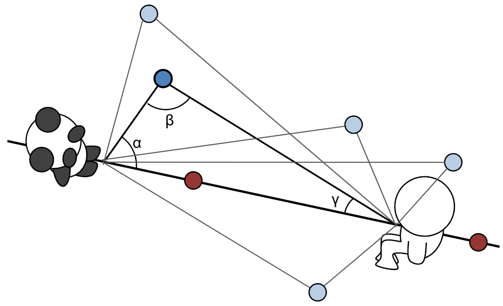

Figure 8: Degree of difficulty with relative angles

4 Discussions

4.1 Consderation of the results

The results of the experiments show that recognition of the pink ball was difficult because of the existence of the purple ball in front of the robot and the user. We frame a hypothesis; the expression of difficulty and effort in pointing gestures can be recognized by a simultaneous and delicate motion of its head to *a different vector from the original indication* when the robot indicate at the difficult angle.

4.2 Behavioral Design for Difficulty

4.2.1 Spatial Difficulty

To express the appropriate level of the difficulty in indication, we tentatively built a model of difficulty in recognition by spatial relationship among the robot, the user, and the object. We supposed the parameters of the difficulty as follows.

1. Number of the targets
2. Relative position among the user, robot, and object

If there were only one object, it might be easier to draw the user's attention than multiple objects as the experimental settings especially in a same direction. A tentative mathematical expression of the difficulty in discriminating two object is shown as follows considering the vectors.

$$D_2 = \frac{2}{\vec{x_1} \cdot \vec{x_2}} \cdot a + b \tag{1}$$

D means the degree of difficulty, $\vec{x_n}$ is the vector from the robot to the n-th object, and a and b are actual numbers.

When the expression is applied to multiple objects with k-pieces, the following expression is hypothesized.

$$D_k = \left(\frac{k}{\prod_{n=1}^{k} \vec{x_n}}\right) \cdot a + b \tag{2}$$

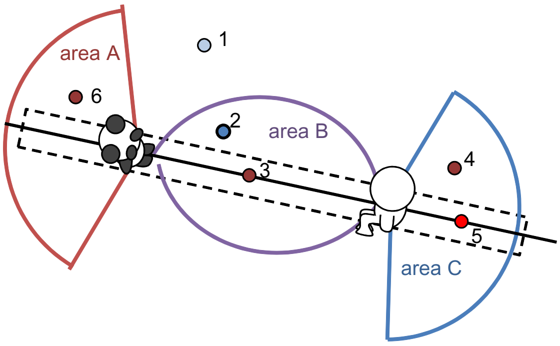

Figure 9: Degree of difficulty in space

Next we considered to build a geometric model as shown in Figure 8 and 9. Figure 8 focuses on a triangle among robot, user, and object. The three angles, α, β and γ as shown in Figure 8, seemed to be related to the difficulty. When β gets smaller, it becomes easier for the robot and the user to have common perception because of their similar vectors. When α and γ get bigger within 90 [deg.], it is also easy to understand the indicated object because the vectors are different from the line connecting between the user and the robot, but the backward areas of the user or the robot are expected to bring higher difficulty.

We improved Expression 2 considering the positional relationship, the following expression is hypothesized.

$$D = \left(\frac{k}{\prod_{n=1}^{k} \vec{x_n} \cdot \vec{y_n}}\right) \cdot a + b \tag{3}$$

$\vec{y_n}$ means a vector from the user to the object.

Figure 9 shows a two-dimensional map based on the difficulty. Our experiment adopted the difficult area C for the pink ball, and the positional relationship between the pink ball and the purple ball in the area B. The results showed that the pointing gesture by the robot's arm is not sufficient to indicate an object at backward of the user.

4.2.2 Behavioral Method Corresponding to Difficulty

We propose to gradually change the robot's behavior based on the calculated value of conjectural difficulty. The variations and repetitions of the behaviors are expected to enable the appropriate level of the expression by limited degree of freedom in the robot's kinetic structure. It is also conjectured that the time duration of the additional delicate motion should affect on the impression of "*effort*." By combining these expressions of the robot, the difficulty could be understood and accepted the effort with a feeling of human-like communication with favorable impressions.

5 Conclusion

In this paper, we proposed an expressive method to indicate a particular object with representation of "effort" of the robot, even when the robot has only few degree of freedom. We conducted the preliminary experiments based on the additional and delicate motion of the robot's head in combination with indicating gesture using its arm. The results of our subjective and objective experiments showed a) the difference of the object sensation by age, b) the strength of the arm for the object indication, and c) the possibility of robot's expression for "effort" using the additional motion of the robot's face toward left side, differently from the direction of the arm. Finally, we suggest an geometric model of difficulty and the gradual expression of "effort" corresponding to the difficulty.

As future works, we consider to verify the expression of difficulty as we proposed. Based on the difficulty, we should evaluate the effectiveness of the different level of the robot's expression for "effort" corresponding to the difficulty.

Acknowledgement

This research was supported in part by KAKENHI 24300047 and KAKENHI 25700021, and the basis of the research achievement was supported in part by KAKENHI 20700106 and the Ministry of Internal Affairs and Communications of Japan when the authors were in ATR IRC.

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