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Physical Contact using Haptic and Gestural Expressions for Ubiquitous Partner Robot

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Abstract— **In this paper, we propose a portable robot to express physical contacts that are parallel to other modalities. It enfolds the user's arm in its arms and tapping the user's arm. The physical contact expressions are generated through a combination of several haptic stimuli and the robot's anthropomorphic behaviors based on its internal state. The aim of our research is building a caregiver-like robot medium. The system was designed for gentle and delicate communication between the user and the robot during a user's outings. The haptic stimuli express warm/cold, patting, and squeezing. Experimental results show that haptic communicative behaviors of the robot increase the intelligibility to the robot's messages and familiar impressions to the robot.**

I. INTRODUCTION

Nuclear families and aging societies have been growing in many countries, so the number of elderly people living alone is also increasing. Some of them need nursing care, and sometimes their activities are restricted for safety's sake. Some physically or psychologically challenged people need to be taken on outings during their rehabilitation. These people need or desire outings, but their families often feel anxiety about their independent activities. The lack of caregivers to provide appropriate support for outings causes social withdrawal of elderly or challenged people.

In order to provide them with relieved outing environment, it is presumed that a ubiquitous service system is effective. There are smart phones and their applications that are based on cloud networks. The context-aware information systems are expected to be suitable for practical use in the support field for elderly or challenged people. However, since the applications cannot perform continuous interactions with the user based on the user's queries or limited push services, it is very difficult to breach the psychological barrier of elderly or challenged people for outings by using only an information service.

On the other hand, many communicative robots, with various behavioral designs, have been developed as daily partners for human life in future. The anthropomorphism and its non-verbal expressions are expected to provide familiar and natural communication by social representation [3], as we communicate using multimodal expressions that are parallel to verbal communications. In caring for elderly or challenged people, it is especially important to use nonverbal expressions to provide smooth communication with understandable message from caregivers. For example, caregivers touch the shoulders of elderly people and look at their faces to confirm their facial expressions before speaking to them. However, it is very difficult to implement physical contact as a communication channel of a daily-life robot.

Since there are many uses of stuffed puppets in the care of dementia patients [1] and traumatized children [2], stuffed toys offer unforced communication for people in difficult situations. As daily-life partners, not only the familiar appearance of the anthropomorphic presence but also natural physical contact should be necessary to remove their psychological burden.

In this paper, we propose a ubiquitous communicative robot which beholds the user, provides ubiquitous services, appropriately gives some messages using physical contact, and cuddles up to the user like a caregiver. In order to implement physical contact from the robot, we combined the anthropomorphic gestural motion of the robot and haptic stimuli via various actuators.

Physical contact in our life have two aspects: familiar expressions of affection and intelligible signals for drawing attention. The former expresses affection by physical contact itself, and the latter draws the other person's attention to the next communication. We propose the stuffed-toy robot using physical contact of two types as follows; 1) enfolding the user's arm with its body warmth ("*affection*") and 2) tapping the user's arm ("*notification*"). Especially for "*notification*," the expression should be done in advance of sending the message. The behavioral model of the robot includes two communication steps: *Initial physical contact* and *Message expressions*. In this paper, we show the effectiveness of basic aspects for the physical contact robot system.

These expressions can be discussed with the aspect of **importance**, that is the gravity of the linguistic contents of the communication. Emotional expressions including affection are shown when people do not have any important message to tell to the other person. Consequently, we prepared a physical contact model corresponding to the importance level of the message as a para-linguistic multimodal expression.

II. RELATED RESEARCH

Haptic stimuli have been adopted for actuators in mobile devices. There are researches of the vibration stimuli as feedback in touch screens of mobile devices [4], [5]. Directional indicators are also discussed using vibro-tactile devices [6], [7], gyro moment [8], [9], and a combination of the skin stretch and vibro-tactile stimuli [10]. These stimuli combined

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with other modalities are expected to provide a push-type notification or realistic information. In this research, we aim to anthropomorphize haptic stimuli as physical contact and to adopt them to a ubiquitous partner robot with intelligible and affective expression as if the robot touches the user.

Considerable researches have been done into the anthropomorphic behaviors, such as affection and attention of robots and agents. The effectiveness of anthropomorphic expressions using gaze, pointing finger, facing, and gazing of the robots and agents has been confirmed in various experiments [11]–[14]. Their multimodal behaviors are effective, however, the behaviors have been discussed without including physical contact by the robot. The combination of physical contact with other modalities enables not only indicating or telling some information but also expressing the robot's own emotion. Tactile communications between the artificial presence and human have instead been developed for input from the user, such as physical interaction of pet robots [15]. Against the flow of the tactile communication, we propose to build a dual-directional physical contact system as a channel of communication. As a first step of our goal, we combined haptic stimuli and anthropomorphic behaviors of the robot in order to enable a feeling of physical contact from the robot.

Communication robots as media have also been developed on the premise of an ongoing communication between people [16], [17]. In these systems, robots regenerate remote messages in an efficient manner. On the other hand, almost all of the robot systems are placed on a desk or a floor, and it is difficult to take them on outings as partners. There is a wearable small avatar robot on the user's shoulder [18]. This configuration enriches informative communication between the human and robot, however, the user cannot look at the robot without turning her/his neck to a severe degree. To solve this problem, we propose to place the robot on the user's arm to give comprehensive communication and appropriate physical contact.

III. System Design

In this section, we introduce a system design for the partner robot using physical contact and report the result of a demonstration experiment. The physical contact of the robot is generated by combining haptic stimuli and gestural motion. Focusing on intelligible and affective communication with the user, we prepared physical contact expressing "*notification*" and "*affection*".

A. Hardware implementation of the robot with physical contact

When the caregivers walk with elderly people during outings, the caregivers touch the elderly people's shoulders or upper arms for better communication. If the robot system is affixed on the user's shoulder, the user would have to severely turn her/his neck, although the control systems could reduce the effects of the user's actions. Additionally, the robot on the user's upper arm can be well appeared when the user moves her/his arm. Therefore, we propose a portable robot fixed on the user's upper arm.

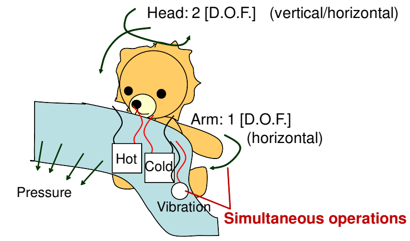


Fig. 1. Hardware implementation of the robot with physical contact

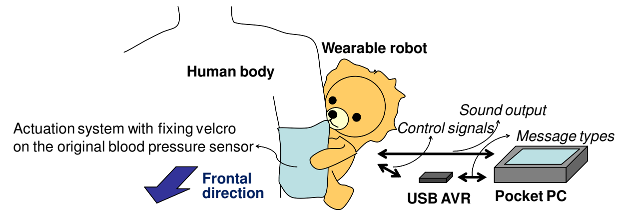


Fig. 2. Fixing and communications of the system

When people communicate with other people, they often use various types of physical contacts to express or emphasize *notification* and *affection*. The recipient of the physical contact can feel various touches from the strength, duration, and body temperature of the other person. Accordingly, we adopted a pressure actuator affixed to the user's left arm, a patting actuator via a vibration motor, and a temperature actuator by two peltier elements (using each heat radiation or cooling section) to the system.

Figure 1 shows the stuffed-toy robot with these haptic actuators. The pressure actuator is separately controlled by pump and bulb of a blood-pressure sensor to increase, keep, and decrease pressure. Using a covering of a blood-pressure sensor cuff, a stuffed-toy robot is attached at the outer side of the cuff. At the inner side of the cuff, a vibration motor and two peltier elements are fixed. One peltier element is used with its heat radiation side, and the other peltier element is used with its cooling side. They are lined up in a row (see Figure 1). For the sake of simultaneous stimulation of the patting actuator and the motion of the robot, the vibration motor is fixed at the position at the robot's left hand.

The robot has three servo motors [VS-S020] for two degree-of-freedom (DOF) at its head in the elevation and azimuthal angles and for one DOF at its left hand in the azimuthal angle. The anthropomorphic robot needs to speak the user in a quiet voice. Accordingly a small speaker that does not have an amplifier is put in the robot's head.

Figure 2 shows how the system structure of our physical-contact robot 8-bit AVR micro-controller [ATmega328] (ATMEL, Ltd.) sends actuator control signals. This testbed implementation is not stand-alone and is connected to a small PC (villiv S5 by BRULE) through serial communication. The sound signals are directly sent to the small speaker [30mmϕ] in the robot's head.

Figure 3 shows a view of the system's use. The fixed part of the system weighs about 250[g], including the stuffed-toy robot, actuators, and battery. Thus the system is expected to be built as a stand-alone device in the future.

Fig. 3. Sample view of the system use

B. Physical-contact communication model

Human-human communication includes not only messages that are "*notification*s" but also affective expressions ("*affection*"). The context-based use of these expressions enriches our communication by conveying different levels of importance. Also, the difference enables natural communication in daily life. For example, a human expresses her/his affective emotions or her/his alerts in different ways based on their importance. If the proposed system provides all the information in the same manner, the user would be confused. Consequently, we investigated a gradual communication model for physical contact corresponding to the importance of the robot's message.

On the other hand, people use multimodal expressions that shift back and forth from the main message (simultaneous or preceding behaviors). When a partner tells a message of "*affection*" or "*notification*" to the other person, the partner draws the other person's attention by touch or gaze in advance before she/he gives the messages. When the partner needs to communicate some urgent messages, the multimodal expressions are represented at the same time because speed and strength in distributing information are necessary.

Figure 4 shows our proposed model of anthropomorphic physical contact with gradual levels of the importance. The robot system provides physical contacts at five importance levels *(Alert, Notice, Recommendation, Conversation*, and *Affection)* corresponding to the immediate/affective aspect of the information by two communication steps, *Initial physical contact* and *Message expression*.

C. Sample operations of the physical contact

Combining the motion of the robot and the haptic stimuli at the same time, our proposed system aims to provide the user a feeling of physical contact from the robot. As shown in Figure 4, we prepared two communication steps as follows.

Step 1–["*notification*"]) Initial physical contact: In order to draw the user's attention to the robot's message, the robot taps the user's arm in *Notice* and *Recommendation*. The patting motion is generated by controlling the horizontal angle of the robot's left hand to the user's arm. The robot's hand approaches the user's arm in 200 ms, keeps the angle for 100 ms, and leave from her/his arm in 200 ms. The patting motion is continuously expressed twice in each expression. The haptic stimuli on the user's arm are 100 ms vibration from the motor with the same timing as the robot's hand.

Step 1–["*affection*"]) Initial physical contact: In *Conversation* and *Affection*, the robot enfolds the user's arm in its arms. The haptic stimuli is generated by controlling both the temperature of the peltier elements and the pressure strength of the cuff. The motion is generated by controlling the head angle of the robot from the direction to the user's front (as shown in Figure 3) toward the user's face (as a trial of engagement) in 600 ms.

Step 2) Message expression: Each message is communicated by the robot's speech. For "*Alert*" and "*Recommendation*", the message expressions include haptic stimuli and gesture motions for context-based appropriate communication.

Thus, the robot appropriately provides context-aware physical contact. For example, when the robot's message is "*Alert*" with high immediacy, the robot expresses both the message such as "watch out" and physical contact at the same time, because the need for initial physical contact decreases. For "*Affection*", the robot just expresses its affective emotion without saying anything.

In the message phase, the robot can generate original physical contact for each importance level. For example, the robot gives cold stimulus to the user as the expression of its own nervous emotion, as if it was in a cold sweat.

Focusing on the initial physical contact expression for "*notification*" and "*affection*," *Notice* and *Conversation* are presumed to be necessary to verify their effectiveness.

D. Demonstration experiment

To gather users' impressions and comments, we performed a demonstration experiment. Most users' comments are favorable since they felt they were touched by the robot, and they want to use it again. In addition, although the user needed to wear the robot including haptic actuators, no user thought that the robot was heavy or who felt a sense of discomfort when wearing it.

On the other hand, comments about the robot's appearance are mixed. Some users felt no difficulty in wearing the stuffed-toy robot, but some users (mainly male users) expressed disapproval while wearing the robot. These results suggest the importance of modifying the appearance, design, and size of the robot according to the user's preference.

In addition, because the robot's motions draw the user's attention. the combination of robot's movement and tactile expression does not necessarily emphasize the robot's expressions. In some cases, users could not notice the robot's tactile expressions. From these results, we need to consider the combination of tactile expressions and robot's anthropomorphic movements.

IV. System evaluations

Focusing on both the intelligibility of the initial physical contact for "*notification*" and the familiarity of "*affection*", we conducted subjective experiments with varied motions of the robot and varied haptic stimuli.

To evaluate the intelligibility of "*notification*", we conducted subjective experiments with and without a) short-term

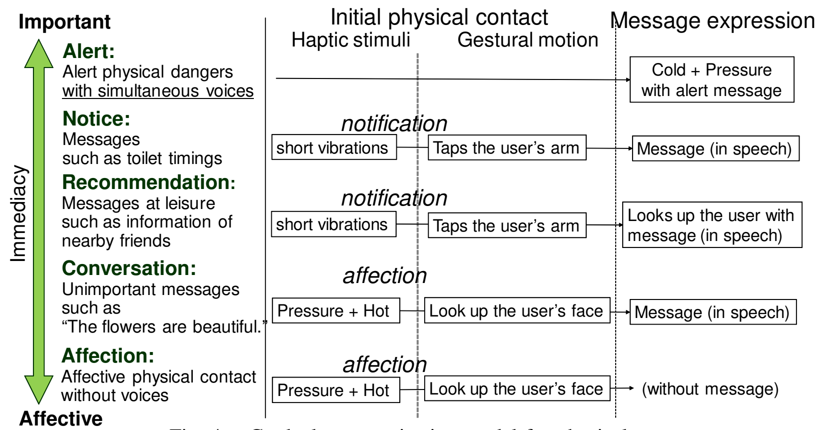
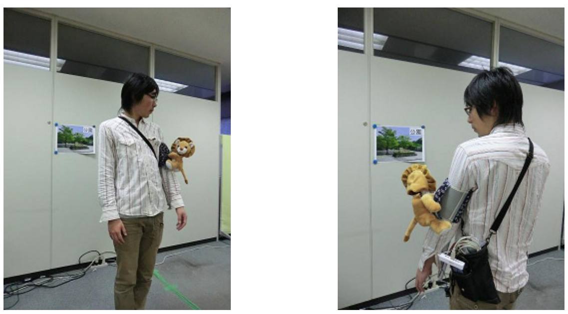


Fig. 4. Gradual communication model for physical contacts



A. "*notification*"
the subject stands backward to the picture

B. "*affection*"
the subject stands in front of the picture

Fig. 5. Sample views of Ex.a and Ex.b

vibrations and b) motions of the robot's left hand that express the robot's notifications as if it is tapping the user's arm.

To evaluate the affective expression of the robot, we conducted subjective experiments with and without a) pressure stimuli and b) motions of the robot's head that express the affection of the robot to the user as if it enfolds the user's arm in its arms.

Subjects: To verify the effectiveness of the robot's physical contacts by comparatively sensitive people as a basis, we recruited twenty-six people aged from nineteen to twenty-five (thirteen females and thirteen males).

Experiment settings: To keep the subject's concentration on the stimuli from the robot as a basis of the system's verification, the experiments are operated while the subject was standing and looking at the robot without any other activities. Figure 5 shows the experiment settings. The subject attached our proposed stuffed-toy robot on her/his left upper arm. A picture of a park in A3 size was stuck on a wall, and the subject tentatively regarded her/his place as if she/he was in front of the park.

*A. Attentive evaluation of intelligibility (**Ex.a**)*

Hypotheses: I-i) Subjects consistently evaluate the expressions of the stuffed-toy robot regardless of the existence of haptic stimuli for "*notification*"; and I-ii) subjects consistently evaluate the expressions of the stuffed-toy robot regardless of the existence of behavioral motions for "*notification*".

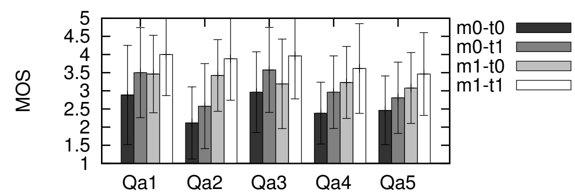


Fig. 6. Results of subjective evaluations (Ex.a)

Conditions: There are four conditions with two factors The first factor of the condition is the patting motion of the robot's left hand as if the robot is tapping the user's arm (`m1`) or without the motion (`m0`). The second factor of the condition is the haptic stimuli of the short-term vibrations (`t1`) or without the haptic stimuli (`t0`).

Procedures and Instructions: The subjects were instructed to stand at the indicated place (1.2 meters from the wall with the picture), and wait for the stimulus of each experiment.

In the experiment for intelligibility, the subject stood backward toward the picture. The robot made the initial physical contact and said "You can see a park at your back." The subject was not instructed to react to the robot. After three seconds from the stimuli, the subject evaluated the expression of the robot in the session.

The experiments in different conditions were held in repeated measurements for each subject with mixed orders of conditions.

Evaluation statements: After each experiment, the subject used a five-point rating scale to evaluate the relevance (5: very relevant, 4: somewhat relevant, 3: even, 2: somewhat irrelevant, 1: irrelevant) of the following statements;

Qa1: the expression of the robot was perceivable;
Qa2: you felt affection for the robot;
Qa3: the robot's expression was easy to understand;
Qa4: the expression was desirable; and
Qa5: you want to use the system in future.

Results: Figure 6 shows the results of means opinion score (MOS) for each statement and Table I shows the results of two-factor repeated measures ANOVA. In the analyses, α, level of significance is .05 and ϕ, degree of freedom (DOF) is (1,25). Underlining means significance, and $\triangle$ indicates

TABLE I
TWO-FACTOR ANOVA RESULTS (EX.A)

	motion		touch		interaction	
	F	p	F	p	F	p
Qa1	5.177	.025	5.94	.017	.026	.871
Qa2	38.3	<.01	4.78	.031	.000	.
Qa3	1.78	.185	9.01	<.01	.111	.739
Qa4	13.8	<.01	5.68	.019	.227	.635
Qa5	10.2	<.01	3.38	.069△	.009	.923

significant tendency.

Qa1 and Qa3 are the statements directly related to intelligibility. The results of Qa1 are significant for both factors of the evaluation, and the results of Qa3 shows significance for the factor of haptic stimuli. Thus both factors of the stimuli are perceived, and it is also conjectured that the haptic stimuli enhance the understanding of the robot's expression.

Qa2, Qa4, and Qa5 are statements of positive impression. The results of Qa2 and Qa4 show both factors' significance. The results of Qa5 show a significance of the factor of "motion" and a significant tendency of the factor of "touch." Thus, both factors of the stimuli can elevate the positive impressions of the robot system.

The results of all the statements show the highest MOS in `m1-t1`. It is expected that the proposed expression with both stimuli can elevate intelligibility and positive impressions. There was not any significance for the interactions, so there is not any particular effect of the combination of both factors. From these results, hypothesis I-i) and I-ii) are rejected.

B. *Attentive evaluation of familiarity (**Ex.b**)*

Hypotheses: II-i) Subjects consistently evaluate the expressions of the stuffed-toy robot regardless of the existence of haptic stimuli for"*affection*"; and II-ii) subjects consistently evaluate the expressions of the stuffed-toy robot regardless of the existence of behavioral motions for"*affection*".

Conditions: There are four conditions with two factors. The first factor of the condition is the patting motion of the robot's head as if the robot is looking up at the user's face (`m1`) or without the motion (`m0`). The second factor of the condition is the haptic stimuli of the pressure on the user's arm (`t1`) or without the haptic stimuli (`t0`).

Procedures and Instructions: The subjects were instructed to stand at the indicated place in front of the picture, and wait for the stimulus of each experiment. The robot showed its affective expression in each condition and said. "Here is a park, I'm happy."

Evaluation statements: The statements for the five-point rating scale are;

Qb1: the robot's expression was easy to understand;
Qb2: the expression was comfortable;
Qb3: the robot showed its affection to you;
Qb4: you felt affection for the robot; and
Qb5: you want to use the system in future.

Results: Figure 7 shows the results of MOS for each statement, and Table II shows the results of two-factor repeated measures ANOVA ($\alpha = .05$, $\phi = (1, 25)$).

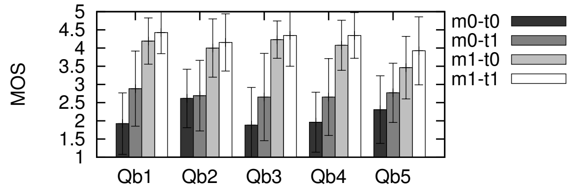


Fig. 7. Results of subjective evaluations (Ex.b)

TABLE II
TWO-FACTOR ANOVA RESULTS (EX.B)

	motion		touch		interaction	
	F	p	F	p	F	p
Qb1	149.	<.01	14.7	<.01	5.52	.021
Qb2	74.1	<.01	.487	.487	.054	.817
Qb3	121.	<.01	5.844	.017	3.193	.077△
Qb4	141.	<.01	9.03	<.01	1.75	.189
Qb5	44.1	<.01	7.06	<.01	.00	.

Qb1 is the statement for the intelligibility of expression as a basis. All the results of both factors and their interaction are significant. The haptic stimuli show the effectiveness especially when the robot does not express the motion of its head by looking up at the subject.

Qb3 and Qb4 are the statements directly related to the affective expression of the robot and the affective impression of the subject. Both factors show significance for each statement, and we could confirm the effectiveness of the affective expression with motions and haptic stimuli.

Qb2 and Qb5 are the statements of positive impression. While the results of Qb5 show significance for both factors, the result of Qb2 for the factor of haptic stimuli is not significant. It is conjectured that the haptic stimuli are expressive, but they did not bring the subject's comfort.

The "motion" factor shows significance through all the statements, and the robot's motion as if it is looking up the subject elevate the evaluations. Accordingly, hypothesis II-i) and II-ii) are rejected.

V. DISCUSSIONS

In the experiments, we verified the effectiveness of "*notification*" (Ex.a) and "*affection*" (Ex.b) by the robot's physical contact as a basis for the physical contact of the ubiquitous partner robot. The experiments were held in the simulation of concentrated situation (Ex.a and Ex.b).

In Ex.a, the main statements related to intelligibility are Qa1 and Qa3, which show significance except the "motion" factor in Qa3. In Ex.b, the main statements related to affection are Qb3 and Qb4, which show significance. From the results of the subjective evaluations, both haptic stimuli and the motion of the robot are effective for intelligibility and affective impression as a basis.

The designed expressions were effective for both intelligibility and affective impression. The "*notification*" expression was effective not only for intelligibility but also for familiar impression as shown in Qa2 and Qa4 of Tables I. The "*affection*" expression was effective not only for the familiar impression but also for intelligibility. Thus, the designed expressions for physical contact were sufficiently intelligible and recognized as the robot's affection for the subject.

Throughout the experiments, the MOSs results were highest in `m1-t1`, as we expected. It is conjectured that adding modalities leads to better impression for the robot, as it does in human-human communication. On the other hand, the "motion" factor was stronger than "touch." It is possible that the effect of the appearance leads strong stimulus even in the peripheral vision of the subject. From the results, we conjecture that not only the visual stimulus but also the anthropomorphic meaning of the motions could draw the subject's attention and positive impressions.

The interactions' results in ANOVAs are not significant except for few results without any prominent MOS value in `m1-ti`. The statements in the experiment are prepared for verification of the basic effectiveness of the system, and the effectiveness of the anthropomorphic physical contact is not directly treated.

The subjects in the experiments were young people to verify the basic effectiveness of the system with comparatively sensitive people. When the robot is used as an alternative to an attendant caregiver, the envisioned users are elderly or challenged people. In addition, the subjects evaluated the system without any other activities. Consequently, we should confirm the effectiveness of the robot's physical contact with elderly people in consideration of wearable system for walking situation [19].

Thus, we could verify the basic effectiveness of the haptic stimuli and the motion of the robot in physical contact as new modalities for the robot. Since caregivers place importance on physical contact when they behold and address people, our proposed system has the potential for reproducing a feeling of physical contact from the robot. We could also consider the detailed possibilities and their future verifications. The detailed designs should not only sophisticate the intelligibility of haptic stimuli as discussed in the device field, but should also contribute the expansion of the expressiveness for affective computing [20].

VI. Conclusions

This paper proposed a portable communicative robot as a ubiquitous partner that expresses physical contact to the user. The system is expected to participate in users' outings as like a caregiver for elderly or challenged people. Based on the importance level of the message, the robot provides the initial physical contact of "*notification*" or "*affection*" combining haptic stimuli and gestural motion before speaking. In the demonstration experiment, we could confirm the physical contact feeling and some positive feedback. From analyses of the subjective evaluations, we could verify the effectiveness of the "*notification*" for intelligibility, and the effectiveness of the "*affection*" for familiarity as the basis for physical contact of the robot. On the other hand, the interactions between factors of the "motion" and "haptic stimuli" did not show any prominent significance, which indicates a particular effect of their combination.

As future works, we need the experiment focusing on the anthropomorphic physical contact with quantitative evaluations and some appropriate statements of the subjective evaluations. The practical use of the system is expected to be explored to conjunct services with outing support applications, such as walk navigation [21] or toilet timing suggestions [22]. It should be also considered to apply the system for beholding children's outings by its familiar interaction of physical contact.

Acknowledgements

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