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Impression Evaluation for Different Behavioral Characteristics in Ethologically Inspired Human-Robot Communication

Takuya Ichikawa, *Student Member*, *IEEE*, Mina Yuki,
Peter Korondi, *Senior Member, IEEE,* Hideki Hashimoto, *Fellow, IEEE*
Márta Gácsi, Mihoko Niitsuma, *Member, IEEE*

***Abstract*—To maintain long-term human-robot communication, a robot behavior model based on the behaviors of dogs in human-dog relationships has been proposed. We apply this model to a robot in a monitoring support system designed for home care. This paper presents an improvement to the model, adding behavioral factors to show different characteristics of the behaviors. We conduct experiments to evaluate users' impressions of the robot behaviors when given different characteristics using a simulator. Our findings show that the subjects had the impressions that we expected based on the factors selected.**

Keywords- human-robot communication; social robotics; ethology; home care application; intelligent space.

I. INTRODUCTION

Intelligent environments are being studied to support and enhance human activity by observing subjects using distributed networked sensors, recognizing human activity, and providing services using distributed actuators such as displays and mobile robots. To observe the dynamic environment, many intelligent devices, called distributed intelligent network devices (DINDs), are placed in an intelligent environment such as that shown in Fig. 1. We named this space "Intelligent Space" (iSpace). The DIND, a basic iSpace element, consists of three basic components -- sensors, processors, and network devices.

Communicating with individual DINDs enables iSpace to apprehend and understand events in this space and to activate intelligent agents such as mobile robots, computer devices, and digital equipment to provide information and services to users based on observed information [1]-[4]. iSpace can obtain multiple humans' positioning at the same time, even if the persons are in different places in space.

To apply iSpace to the elderly monitoring support system, after detecting events in the environment, iSpace

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Takuya Ichikawa, Mina Yuki, and Mihoko Niitsuma are with Dept. of Precision Mechanics, Chuo University, 1-13-27 Kasuga, Bunkyo-Ku, Tokyo 112-8551, Japan (e-mail:niitsuma@mech.chuo-u.ac.jp).

Peter Korondi is with the Dept. of Mechatronics, Optics and Applied Informatics, Budapest University of Technology and Economics Budapest, Hungary.

Hideki Hashimoto is with the Dept. of Electrical, Electronic and Communication Engineering, Chuo University, 1-13-27 Kasuga, Bunkyo-Ku, Tokyo 112-8551, Japan.

Márta Gácsi is with the Dept. of Ethology Eötvös Loránd University Budapest, Hungary.

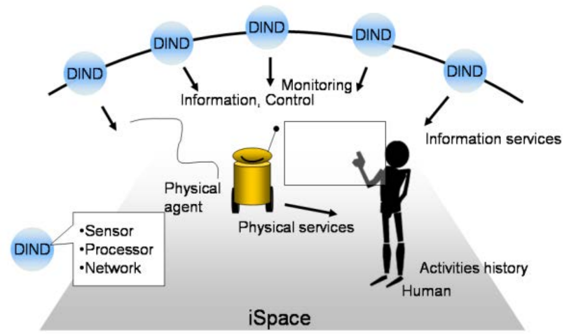


Figure 1. Intelligent Space concept

needs to inform caregivers of the situation without disturbing their primary activities.

Since a caregiver usually moves in space, approach and evaluated implemented robot behaviors through live experiments with subjects [11]. This paper presents an improvement of the model, adding behavioral factors, which were derived from factor the information must be presented at any location. Mobility is required of a physical agent of iSpace. We therefore use a mobile robot to provide monitoring information for a care assistant.

Robots have been used to deliver information services for users, for example, daily information delivery [5], a cooking procedure support system [6], and a guide robot in a museum [7]-[9]. In the cooking support system, the study suggests that robot behavior is useful to present location information, in particular, to the user. The robot is also useful to increase the pleasure of cooking. The robot exhibits a behavior based on a user's cooking procedure. In the case of the information delivery robot [5], the robot was evaluated compared to a computer display. The experiment showed that users felt a sense of emotional attachment and attended more carefully to the robot compared to a display. Accordingly, we consider that robot behavior is useful and effective to deliver information to users. Robot behavior models depend, however, on user applications.

When we consider continuous use of the robot for a long time, relationship building between users and the robot becomes more important [10]. The robot is required to behave so as to build social relationships with users. The robot is also required to behave autonomously based on the current situation in a space in order to present a monitoring result. We therefore need to consider a robot behavior model that enables the robot to communicate with people and to behave autonomously while reflecting the situation in the environment. To address this issue, we previously proposed a robot behavioral model based on an ethologically inspired analysis of observations of dogs' behaviors, to show different characteristics in the behaviors [12]. We conduct experiments to evaluate users' impressions of robot behaviors when exhibiting different characteristics. The paper is organized as follows: Section 2 describes a monitoring system based on iSpace. Section 3 presents a robot behavior model based on an ethological approach. Section 4 shows experiments to evaluate users' impressions. The last section concludes the paper.

II. iSPACE-BASED ELDERLY MONITORING SUPPORT SYSTEM

A. Overview of monitoring of elderly safety

We apply iSpace observation functions to monitoring elderly persons' safety in order to reduce care assistants' monitoring burdens. To evaluate an elderly person's safety, we decided to detect two kinds of situations: the first one is "entering unsafe areas alone"; the second is "lying down on the floor". To detect the events, we define four types of regions. The first region is an "unsafe area", which means that an elderly person is not allowed to enter alone (REGION 1). The second region is defined as a region in which people do not usually lie down (REGION 2). The third region is any area within the observation zone that is not one of the two kinds of areas previously described (REGION 3). The last region is outside of the three areas (REGION 4). In other words, REGION 4 can be defined as the space outside the zone of observation.

To evaluate an elderly person's situation, we observe the location of the elderly person and a care assistant using Furukawa Co., Ltd.'s ZPS ultrasonic positioning system. The three-dimensional position of an ultrasonic transmitter can be obtained beneath the ceiling on which ultrasonic receivers are installed. Therefore, each person needs to wear a transmitter. Persons can be identified based on the ID number of the transmitter.

B. Details of the observation

We focus on two situations to be detected in an elder care environment: whether or not the elderly stays in the same room with the care assistant, and whether or not the elderly person lies down on the floor. Here, the methods used to obtain basic information and detect the situations are explained.

1) Detection of whether or not the elderly person stays in the same room with the care assistant: If the transmitters of both the elderly and the caregiver can be detected within a certain distance, we conclude that the elderly person stays with the caregiver. If either person's position is obtained outside of the predefined areas or either transmitter cannot be detected, we conclude that they are separated and stay in different places. In addition, based on the position of the elderly person, we can detect the situation when the person enters REGION 1.

2) Detection of whether or not the elderly person lies down on the floor: This can be detected based on the distance from the floor to the transmitter. The position of the z-axis represents this information. Therefore, we specify a threshold value to detect when the situation has occurred.

The iSpace needs to deliver the observation to the care assistant. We integrate a mobile robot into the monitoring system as a physical agent of iSpace.

III. ETHOLOGICALLY INSPIRED ROBOT BEHAVIOR FOR MONITORING SUPPORT SYSTEM

To continue the use of a robot for a long period of time without stress or loss of interest in the robot, social relationships between the user and the robot, not just the functionality of the robot, become more important. At the same time, the robot is required to show monitoring information to users. To realize this, we focus on human-dog relationships [13]. A dog can behave in response to not only its own situation but also to situations surrounding it, and people can interpret dogs' behaviors with regard to the situation (e.g. see seizure-alert dogs). If people can interpret dogs' behaviors, they can expect corresponding situations. In addition, what is important that dogs show attachment to their owners [12]. It is therefore suitable for the robot behavioral model to show both monitoring information and attachment to users.

Kovacs et al. have presented an ethologically inspired human-robot interaction model in order to achieve naturalistic interactions between robots and humans [14]. The main importance of this study is considered to be the proposal of a mathematical model based on a verbally described ethological model. They introduced state variables to describe the inner states of a dog according to environmental context. The original model of dogs' behaviors has been investigated in the "strange situation test" [14]. In this test, a situation in which a dog is stressed by an unfamiliar environment and encounters an unfamiliar person is considered. This model is appropriate for our model to show attachment to users in stressed situations. We therefore applied it to the robot behavioral model as the base model considering the caregiver as the owner and the elderly in the role of the unfamiliar person.

The expected situation in the monitoring application, however, is slightly different from the original model; that is, it takes place in a nursing environment where the people should be known and familiar to the robot. The factors leading to expressed differences in the behaviors toward the owner and a stranger in dogs are known: behavioral characteristics of dogs depend on the factors of *attachment to owner*, *sensitivity to anxiety* and *acceptance of stranger* [14]. This Therefore, besides the role of the owner (caregiver) we distinguish two types of persons; we recognize an elderly person as a familiar person who evokes a high level of *acceptance of stranger*, and a stranger as an unfamiliar person who has a low level of *acceptance of stranger*. The elderly and strangers can be distinguished from each other based on the level of *acceptance of stranger*.

To address this, we add the behavioral factors to show the robot's behavioral characteristics in the previous model.

A. Ethologically inspired robot behavioral model

The proposed behavioral model has three inner states to reflect situations in the environment: *miss* that represents the level of stress brought on by separation from the owner/caregiver; *anxiety* that represents the level of stress from the elderly's situations; and *explore* that indicates the level of the desire to look around the room. The inner states are updated based on the observation by iSpace. Then, an appropriate robot behavior is selected from the behavioral set. The selection rule and the behavioral set are defined by scientific knowledge of the social behavior of dogs. For example, there are two main behaviors, "*dog explores the room*" and "*dog goes to the door*", which dogs exhibit according to the situation. The "*dog explores the room*" behavior means a dog exploration activity in which the dog looks around in an unknown environment. This behavior is expected to be shown just after a dog enters the room. The "*dog stands by the door*" behavior is defined as a simple dog activity in which the dog goes to the door and then stands/sits in front of it. This behavior might be shown when the dog is missing its owner who has left the room.

To distinguish robot behaviors from real dog behaviors, behavior codes are expressed using "RDog". Table I shows the robot's behavioral set based on the "strange situation test" and leading behavior observed from the "hidden food test" [15]. In the monitoring support system, we assign the role of the dog's owner in the original model to a caregiver who provides home care (Person C). An elderly person who is a care receiver is called Person E. Other persons are recognized as strangers in the original model, who have a low level of *acceptance of stranger*.

TABLE I. BEHAVIORAL SET

	Behavior label	Behavior
Attachment behaviors	RDogExplores	Exploring in the room
	RDogPlaysWithPersonC	Playing with Person C
	RDogGoesToDoor	Standing by at the door
	RDogGreetsPersonC	Greeting Person C
	RDogGoesToPersonC	Standing by at Person C's side
Leading behaviors	RDogGetsAttention	Getting Person C's attention
	RDogShowsDirectional Signal	Showing the direction toward a target place

Rule bases to determine the levels of *anxiety*, *explore* and *miss* are defined. The level of *anxiety,* "RDogAnxiety Level", is determined based on evaluation of the elderly person's location and the distance between Person E and Person C as follows. Here, the text in italics is the linguistic term of the rule base.

If PersonEInREGION1Alone = *True* **Or**
PersonEInREGION4Alone = *True* **Or**
PersonEDownInREGION2 = *True* **Then**
RDogAnxietyLevel = *Increasing*,
Otherwise RDogAnxietyLevel = *Decreasing*.

If DistancePersonCAndPersonE = *near* **Then**
RDogAnxietyLevel = *Decreasing*.
If PersonCInREGION4 = *True* **AND**
PersonEInREGION4 = *False* **Then**
RDogAnxietyLevel = *Increasing*.

In the basic model [12][13], if the robot is far from the stranger and near the owner, then the level of *anxiety* decreases. However, in this model, we defined that if Person C is near Person E, then the level of *anxiety* decreases. The level of *anxiety* does not depend on the distance between a robot and Person E in this model. The rate of the *anxiety* level change can be defined according to the types of the regions (REGION 1 - 4). If the rate of *anxiety* change was set as high, "RDogAnxietyLevel" would increase quickly; therefore, the robot could immediately exhibit a behavior according to the change of the situation. On the other hand, if it has a low rate, the robot allows the elderly person to remain there for a relatively long term.

The level of *explore,* "RDogExploreLevel", depends on the size of the unknown regions in a room and the level of *anxiety*.

If RatioUnknownRegion = *Small* **Then**
RDogExploreLevel = *Decreasing*.
If RatioUnknownRegion = *Large* **AND**
RDogAnxietyLevel = *Low* **Then**
RDogExploreLevel = *Increasing*.

"RDogExploreLevel" would not be changed even if "RatioUnknownRegion" was *Large* so long as "RDogAnxietyLevel" was *High*.

Rules related to the level of *miss,* "RDogMissLevel", are basically same as in the basic model. The ratio of decrease in the level is determined based on the factor of *attachment to owner*. Higher level of *attachment to owner* shows a smaller ratio of decrease.

If PersonCInREGION4 = *True* **Then**
RDogMissLevel = *Increasing*.
Otherwise RDogMissLevel = *Decreasing*.

In addition to the model, we add a tuning mechanism of the robot's behavioral characteristics based on dogs' behavioral factors: level of *attachment to owner*, level of *acceptance of stranger*, and level of *sensitivity to anxiety*. Based on the levels of the factors, we define increase-decrease rates for each inner state. The level of *acceptance of stranger* is given high value to enable the robot to show friendly behaviors to the elderly (unfamiliar persons in the original model).

We built a simulator to evaluate robot behaviors in a variety of situations. The user interface of the simulator is shown in Fig. 2. It can show the room, positions of two persons and the robot, a label of running behavior, levels of the parameters, and values of dogs' behavioral factors. Users can control their positions and behavioral factors via the computer mouse. The red triangle shows Person C, and blue is Person E. Light blue coloring of the cell represents the history of the robot's movement.

Dark pink areas show REGION 1 in which Person E is forbidden to enter alone. Light pink areas show REGION 2 in which people do not usually lie down. Therefore, if Person E enters REGION 1 or lies down in REGION 2, the level of *anxiety* increases.

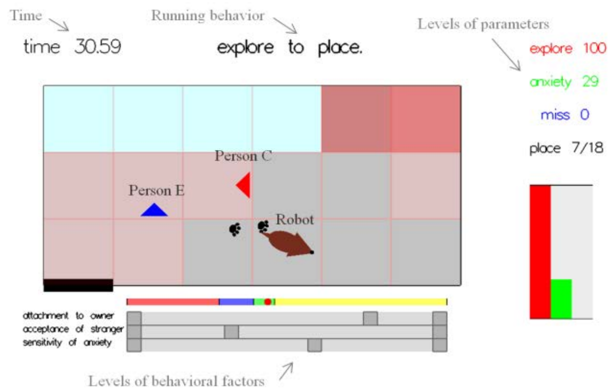
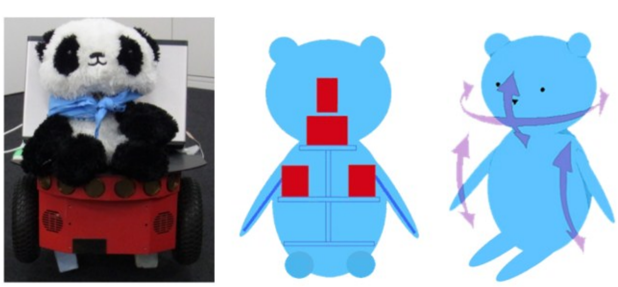


Figure 2. User interface of the simulator. On the interface, users of the simulator can confirm which behavior is running and the levels of the parameters with the bar chart.

B. Implementation of Robot Behaviors

We implemented the robot behaviors shown in Table I. The hardware of the robot consists of the upper body and the mobile platform as shown in Fig. 3. The upper body is modified to improve leading behavior. Specifically, what is important to show leading behavior from the viewpoint of the robot's embodiment is that the robot can indicate the direction of a target place using the body while the head faces in the direction of the person. To realize this, the upper body is implemented using a stuffed toy as shown in Fig. 3 (a), which can move the head as shown in Fig. 3 (b). The robot can also move the arms.

From the viewpoint of the mobile platform, a suitable goal position of movement and velocity for each behavior should be given. Using the head part, the robot expresses not only each behavior but also inner states based on the level of the parameters *miss*, *anxiety* and *explore.* Movement of the mobile platform in each robot behavior is described as follows.



(a) (b)

Figure 3. Physical agent in the iSpace-based monitoring system. The robot consists of a mobile platform (Pioneer3-DX) and an upper body: (a) whole body (b) upper body; arrangement of motors and degrees of freedom of the robot. Red boxes show RC servo motors.

a) RDogExplores: The robot explores in the room. A target to be explored is selected stochastically from among the caregiver, an elderly person, and places based on the levels of *attachment to owner*, *acceptance of stranger* and the history of robot movement. After selecting a target, the destination of the robot is determined within the colored area around the target, as shown in Fig. 4. And if Person C stays in REGION4, "explore to owner" in Fig. 4 (a) is not selected. In the same way, if Person E stays in REGION4, "explore to stranger" in Fig. 4 (b) is not selected. Passive behavior corresponds to staying in the base area in Fig. 4 (d). When "RDogExplores" is selected and both levels of the behavioral factors are low, the frequency of passive behavior increases.

b) RDogPlaysWithPerson: This behavior is important to give users an opportunity to communicate with the robot directly. To realize direct communication between a user and the robot, we implement this behavior as "playing with a person using a ball". The robot follows a yellow ball using a color camera, and then brings the ball to the person. This behavior is shown when a person sits down to start playing with the robot.

c) *RDogGoesToDoor:* The robot goes to the door and stays there. The door's position is given in advance.

d) RDogGreetsPersonC: The robot follows Person C with glee. A goal position for the movement is updated to the current Person C position.

e) RDogGoesToPersonC: The robot comes close to Person C and stays in the vicinity of the person.

f) *RDogGetsAttention/RDogShowsDirectionalSign-al:* Leading behavior consists of two actions. First, the robot tries to get Person C's attention, so it approaches Person C and stands in front of the person orienting at the person. After that, the robot goes to a target with Person C. If Person C does not move to the goal with the robot, the robot stops and indicates the direction to the goal using the rotation movement of the body, and turns the head to the person until the person starts to move.

The robot behaviors are selected based on the rules shown in Table II. Threshold levels α, β, γ, and ε are design parameters.

Motions of the upper body are defined to show each behavior and the inner states of the robot. Table III shows the implementation of each behavior.

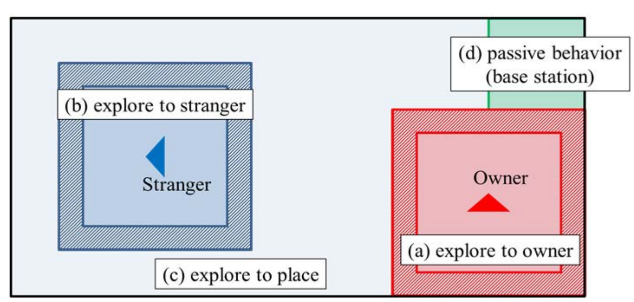
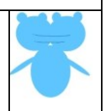
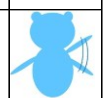
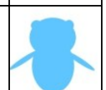
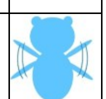


Figure 4. Target areas for each exploring behavior. A target position is chosen within the area based on the target to be explored.

TABLE II. BEHAVIORS AND RULE BASES FOR BEHAVIOR GENERATION

Behavior label	Rule
RDogExplores	otherwise
RDogPlaysWithPerson	user's action
RDogGoesToDoor	$miss \geq \alpha$ %
RDogGreetsPersonC	α % $\leq miss \leq$ 100% when *miss* level is decreasing
RDogGoesToPersonC	$anxiety \geq \beta$ % and $explore \geq \gamma$ %
RDogGetsAttention/ RDogShowsDirectionalSignal	$anxiety \geq \varepsilon$ % when *explore* level is decreasing

TABLE III. IMPLEMENTATION OF ROBOT BEHAVIOR

Behavior	Movement of the mobile platform	Motion of the upper body	
RDogExplores (explore to place/owner/stranger)	Move to a target	Rotate the head and gaze at the target	
RDogPlaysWith Person (play with owner/ stranger using a ball)	Find a yellow ball and bring it to the person	Move one arm up and down	
RDogGoesToPerson C (go to owner)	Move close to Person C and stay there	Lower the arm	
RDogGoesToDoor (go to door, stand by door)	Go to the door and stand by.	Lower the head and arms, and look at the door	
RDogGreetsPersonC (greet owner)	Follow Person C	Move the arms up and down	
RDogGetsAttention/ RDogShowsDirectionalSignal (leading behavior)	Move to Person C, then go to a target together. If Person C does not come along, the robot returns to the person.	Turn head towards Person C to get Person C's attention. Look at a place to show the direction to the target.	

IV. EXPERIMENT

As noted in section III, Person C can influence the behavioral characteristics of the robot through the behavioral factors. What is important here is whether the behaviors correspond to impressions that the person expects to have. Differences between various characteristics of the robot behaviors will be observed in the target selection for "RDogExplores" and the frequency of "RDogGoesToPersonC". For example, an elderly might be selected often as a target to be explored if the robot has a high level of *acceptance of stranger*. We conduct a preliminary experiment to confirm this using the simulator. Robot behaviors according to two different characteristics are generated using the simulator and captured on video. Subjects provide their impressions of the robot behaviors while viewing two different videos. Settings of the characteristic parameters in two cases are shown in Table IV.

TABLE IV. PARAMETER SETTINGS FOR TWO CASES.

	attachment to owner [%]	*acceptance of stranger* [%]	*sensitivity to anxiety* [%]
Case A	80	20	50
Case B	20	80	50

Adjective keywords from the questionnaire to evaluate subjects' impressions are shown in Table V. We selected the keywords referring to words used for expressing behavioral characteristics of a dog. Subjects indicate the strength of their level of impression using a five-point evaluation scale, with five being the highest score (most appropriate) and one being the lowest.

TABLE V. IMPRESSION KEYWORDS FOR EXPERIMENT.

Impression keywords	
curious	friendly
cautious	faithful
timid	independent

In case A, since *attachment to owner* is higher than *acceptance of stranger*, "cautious", "faithful", and "timid" might receive high scores. In case B, since *acceptance to stranger* is higher than *attachment to owner*, impression keywords that we expect to score highly are "curious", "friendly", and "independent".

A. Setup

Fifteen subjects (male: 12, female: 3, and their ages ranged from 21 to 23 years) participated in the experiment. The subjects were uninformed about behavioral factors. They watched the videos of case A and case B. In order to evaluate differences in behavioral characteristic parameters, two videos were created for each scenario. Table VI shows the scenarios. In the initial state, Person C moves in the room with the robot freely. After that, a visitor regarded as a stranger enters the room. Table VI also indicates expected robot behaviors in each situation.

The subjects are divided into two groups, and one group begins watching the video of case A first, after that they watch the video of case B. Another group performs the experiments in reverse order.

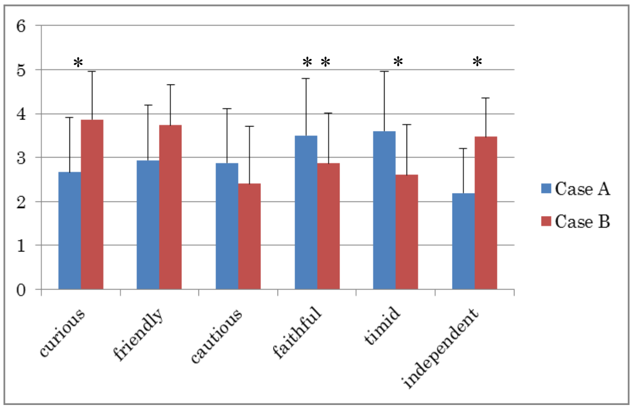
TABLE VI. BEHAVIORS AND RULE BASES FOR BEHAVIOR GENERATION

(1) Person C moves freely in the room with robot. (2 min) (When the person is sitting down, the robot will play with the person.)
(2) A visitor enters the room. Person C and the visitor move freely. (1 min) (When the visitor enters the room, the level of *anxiety* increases temporarily. As a result, the robot will approach Person C.)
(3) Person C leaves the room. (The level of *miss* increases and the robot will go to the door.)
(4) Person C returns to the room. (The robot greets Person C while the level of *miss* exceeds α.)
(5) After 1 minute, visitor leaves the room. (The level of *anxiety* increases and the robot starts the leading behavior.)

B. Experimental Result and Discussion

Fig. 5 shows the average scores of the impression keywords that the subjects evaluated. We used t-tests to evaluate significant differences between cases A and B.

The keywords "faithful" and "timid" received a higher average score in case A compared with case B. In contrast, "curious" and "independent" received a higher average score in case B compared with case A. The results showed significant differences between the cases. From this, we found that the subjects experiences different impressions from the robot behaviors. The ratings of the impressions were also considered appropriate. Thus, the robot behaviors based on the behavioral factors functioned appropriately to convey the behavioral characteristics to people without any knowledge about the robot.



* : $p < 0.05$, * * : $0.05 < p < 0.1$

Figure 5. The average value of all subjects.

V. Conclusion

This paper presented human-robot communication for monitoring support systems for the purpose of home care support. We use a distributed sensor system called iSpace for the monitoring of elderly safety. The iSpace system, which consists of DINDs, is useful to observe an environment including multiple persons in different places. To deliver monitoring results to a caretaker, we use a mobile robot.

In this paper, we presented a robot behavior model based on dogs' behaviors in human-dog relationships. The model was improved by adding behavioral factors to show different characteristics in the behaviors. We conducted experiments to evaluate users' impressions of robot behaviors when displaying different characteristics. As a result, we confirmed that the subjects experienced the impressions that we expected based on the factors set up. The subjects could recognize the characteristics from the robot behaviors without any knowledge about the robot. When applying the model to the monitoring support system, behavioral factors can be modified to fit a caregiver's preference.

The experiment was performed using the simulator to display all of the events in the room. The viewpoint of the subjects was different from a live experiment using a live robot. When a user will play the role of the caregiver or an elderly, we will evaluate users' impressions in future work.

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