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Enhancement of Attachment Behavior Model for Social Robot to Adapt in Daily Living Environments

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Abstract— **Recently, social problems associated with a sense of isolation among elderly adults have been highlighted. To address this problem, we propose a long-term human-robot communication program inspired by human-dog relationships. An Etho-engine was improved upon to provide robot accommodations for access within rural regions. We generalized the robot's inner states and updated rules governing decision-making based on interactions with external situations. Additionally, to develop robot preferences for a person other than the owner, a "non-owner" was defined as being initially unfamiliar, with gradual acceptance being updated according to interaction histories and relationships between the non-owner and the owner. Experiments were conducted to evaluate the communication model. We discuss the effectiveness of this modified Etho-engine based on the experimental results.**

Keywords: ***human-robot communication, social robot, ethologically inspired robotics***

I. INTRODUCTION

In recent years, a sense of isolation or lack of exercise among elderly individuals has been noted. Issues related to isolation are important given research showing increased risk for dementia among elderly adults due to a lack of social contact [1].

Therapy is a well-known approach for treating elderly adults both suffering from dementia or experiencing a sense of isolation. One common therapeutic style includes animal-assisted therapy. Animal-assisted therapy is recognized as an effective approach for improving mental health. For example, memory benefits have been observed through tactile stimulation with certain animals. However, animal-assisted therapy has some issues. For instance, the time needed to rear and educate animals can be extensive. Hygienic conditions of the therapeutic environment can also be a challenge. Moreover, people who are allergic to certain animals cannot receive animal-assisted therapy. Therefore, recent research has shifted toward a more pragmatic therapeutic option: robot therapy.

Robot therapy using the seal robot, PARO, has been effective in imitating the emotions facilitated by animal-assisted therapy [2]. Babyloid has been shown to be another suitable therapeutic robot. These robots arouse various feelings among their users when the robot is in a caretaker role. Through these interactions, the user becomes more relaxed and experiences less loneliness [3]. One limitation of this past research, though, is that previous studies have not discussed continuous robot usage during everyday-life scenarios.

For reducing one's sense of isolation, it is important that human-robot communication is performed over the long-term in a real-life environment. In order to achieve continuous long-term communication, the social relationship between a caretaker and a robot is important. Thus, in the present study, we aim to reveal a solution for improving one's sense of isolation through human-robot communication. As an analog for this type of long-term relationship, we focused on human-dog communication.

Our focus on human-dog relationships comes from the fact that dogs are able to build and maintain social relationships with humans over the long term. Studies on dog ethology have clarified characteristics of human-dog communication via the cognitive and social abilities dogs display when their behavior is observed. Therefore, a dog behavioral model has been devised through objective, ethological observations [4].

Dogs tend to display attachment behaviors toward their owners [5]. Such behaviors include preferences for their owner as a secure base. These attachment behaviors stem from a developed social relationship. Therefore, for the present study, dog attachment behaviors were used as a model for a social robot developing sustained, human-robot communication.

In our previous study, we proposed an attachment behavior model for a social robot based on three inner states: *miss*, *anxiety,* and *explore* [6]. Parameters for allowing a dog to express his/her stress was provided by certain environmental situations. For example, *explore* was used for expressing stress emerging from an unknown source. *Miss* represents stress emerging from the separation from his/her owner. *Anxiety* is the stress that is facilitated by strangers. Updated rules for these parameters are shown in Table 1. Additionally, three factors were introduced to reveal differences in robot behavioral characteristics. The three factors include degree of attachment to the owner, acceptance of a stranger, and sensitivity of anxiety. We termed this ethologically inspired behavioral model the "Etho-engine." The robot shows attachment behaviors based on the Etho-engine, and a conventional model for attachment behavior is shown in Table 2.

Since the Etho-engine was created based on the "strange situation test" [5], conditions supported by this model are very restricted. In simple terms, the test is conducted with an owner and one unfamiliar person in an unfamiliar room. This setup is considered minimal for imitating a social environment. However, the robot's daily-living environment will be more complicated. For example, there might be both familiar individuals and other objects in the environment. In order to deal with this issue, we propose a new, enhanced Etho-engine that allows a social robot to communicate with various objects.

Table 1. Rules for the state-transition

[*miss*]

- owner is in the room: **Decrease**
- owner is not in the room: **Increase**

[*anxiety*]

- stranger is in the room for a minute: **Increase**
- stranger is not in the room: **Decrease**

[*explore*]

- Before the robot explores unknown areas: **Increase**
- After the robot explores unknown areas: **Decrease**

II. IMPROVING THE ETHO-ENGINE

Caretakers reporting a sense of isolation were determined as robot owners. Two approaches for human-robot communication were considered. One is a direct approach; here, a robot directly interacts with a caretaker. The other approach is an indirect approach; here, a robot promotes an interaction between the caretaker and other persons (non-owners). To promote an interaction between a caretaker and non-owners, the caretaker's social relationships are enhanced, which can help decrease a sense of isolation. Therefore, the indirect approach should be considered.

The direct approach has been well studied, and previous Etho-engines are useful for this approach. However, the Etho-engine cannot facilitate the indirect approach. The Etho-engine is able to recognize a non-owner and generate owner-preference behaviors. However, the relationship between the robot and non-owner is fixed. Therefore, even though the robot will interact with the non-owner several times, the robot never changes its behaviors. Moreover, in order to show an owner preference, the robot never actively engages with the non-owner.

To promote an interaction between an owner and non-owner, the Etho-engine should treat the non-owner as initially unfamiliar and then recognize the non-owner as familiar based on experiences with interactions between the owner and non-owner. Additionally, the robot needs to actively interact with a familiar person. For example, a dog might display greeting behaviors toward a familiar person. To accomplish this, we present an enhanced Etho-engine.

A. Improving inner states

As shown in Section 1, the previous Etho-engine has three inner states. The inner states are defined to express stresses from behavioral factors, including the owner, an unfamiliar person, and an unfamiliar environment. As shown in Table 2, the robot shows preferable behaviors based on the "*miss*" level; however, the robot shows negative behaviors based on the "*anxiety*" level. This model works well when the person-roles are fixed. However, robot behavior orientations are also fixed. To address this problem, we define the inner states, "*miss*" and "*anxiety*," as expressing stresses from one behavioral factor. This means that stresses from an owner, a non-owner, a room, and an object (i.e., ball) are expressed using two inner states, respectively.

Improving upon the Etho-engine enables the robot to interact with various people and objects. In addition, the robot is able to show positive and active behaviors not only toward the owner but also toward other, non-owners.

In addition to previous inner states, rule descriptions for evaluating events used to express stresses are also restricted. These rules are able to describe one-to-one correspondence with each factor because the number of factors is very limited. Therefore, stresses should be evaluated based on a generalized method for dealing with changes to behavioral factors. Moreover, an update on inner states for the conventional Etho-engine is conducted under restrictive situations, including when the owner goes into the room. However, situations around the robot are constantly changing within the room. Even though an owner and a robot stay in the same room, and the situation is observed as if nothing has changed, the distance between the owner and the robot (or the time during which the owner is far away from the robot) is important for evaluating the situation.

Table 2. Conventional Etho-engine

State of the robot and environmental situations	Robot's behavior	Robot's action
Owner goes out of the room	Go to door	Go to the door and stand by
Miss is high Owner goes into the room	Greeting	Move close to the owner and follow owner
Anxiety is high Stranger goes into the room	Go to owner	Move close to the owner and stay there
Explore is high	Explore the area	Move to a target
All inner states are low	Passive behavior	Go to the base station

Therefore, inner states should be updated sequentially. Thus, we introduce a method for evaluating a situation and obtaining an inner state as follows in (1).

$$s_i = \alpha_j \left(d_j(t-1) - d_j(t)\right) + d_j(t) \cdot f_{ij}(t) \qquad (1)$$

Here, s_i is a value for expressing stress. i is an identification symbol for the inner state, and j is an identification symbol for the behavioral factor. α_j is a design parameter, and $d_j(\mathrm{t})$ is the distance between the robot and a person j or the frequency of an object/place used by j. $f_{ij}(t)$ is a time function for providing a value change characteristic. Here, when a person is absent from the room, distance cannot be calculated. At this time, a large fixed value is given.

Improvement to the inner states enables a robot's positive behavior. For example, the robot will greet a person when the person, who is recognized as a familiar person, goes into the room. Additionally, since the inner states are updated sequentially, the robot will move close to the owner when the owner has been further away for a while, even if the owner had stayed in the room.

When generalizing the inner states, robot interaction targets are not limited to an owner and a person. The robot is able to interact with a tool or with a person through the tool.

Playing with a person is recognized as an important interaction between a human and a dog during a strange situation test. This is because a dog's preference orientation can be clearly expressed. Therefore, we introduce play behaviors using a ball with the new Etho-engine. Playing with a ball is an interaction that is initiated by a person. Therefore, the robot will show a preference toward the person if not playing with another. We predict that this task will elucidate preference differences between certain individuals.

A person accepted by the robot will be allowed to play with the ball. The robot will play with a person when the robot's acceptance of that person is beyond a certain threshold, and the robot's inner states are low. That is, playing with a ball is performed between the robot and a person who is trusted by the robot. In contrast, conditions where the robot plays with the owner will emerge when the robot's inner states are low.

Table 3 Improved Etho-engine

State of the robot, surrounding environment			Robot 's behavior
Object	Stress	Object is in the room?	
Owner	*Miss*: high	Yes; into the room	Greeting owner
		Yes	Missing
		Yes	Go to door
Stranger	*Anxiety*: very high; *acceptance*: low	Yes or No	Go to owner*
	Anxiety: high; *acceptance*: low	Yes	Explore to stranger*
	Miss: high; *acceptance*: high	Yes; into the room	Greeting stranger*
Ball	*Anxiety*: low	Yes	Playing**
	Miss: high	Yes	Encouraging
-	all inner states are low	-	Passive behavior

*If the owner is in the room, the robot performs the behavior.

**If the stranger is accepted by the robot, the stranger can play with the robot.

B. Improving behavioral decisions

The previous Etho-engine engages in a behavior toward a person when an event occurs. This means that the Etho-engine is recognized as an event-driven behavior generator. However, to promote interactions with a person, the Etho-engine produces a behavior independent from the event, depending on stress levels.

Therefore, we improved a behavioral decision based on the robot's inner states and the situation. The enhanced Etho-engine is shown in Table 3.

C. Relationship with a person other than the owner (non-owner)

To show a preference for a person other than the owner, the robot needs to distinguish familiar persons from others. We have introduced a robot's behavioral characteristics [7] and realized that robot behaviors show different preferences for certain people. Specifically, we use the degree of attachment to the owner, degree of acceptance for a non-owner, and the degree of sensitivity. The degree of acceptance for a non-owner is important in determining a familiar person. However, there is no mechanism for changing the degree of acceptance toward a non-owner in the previous Etho-engine. Therefore, we suggest that a person be defined as unfamiliar, initially, and then the degree of acceptance is updated based on the interaction history and relationships between the owner and non-owner.

To initiate an interaction with an unfamiliar person, the robot engages in exploring behavior. This behavior is for becoming directly acquainted with the stranger. The interaction is evaluated by focusing on the stranger's reactions. For example, if the stranger does not react negatively or violently toward the robot, acceptance increases. However, if the person acts negatively or violently (even if the robot is not exploring), acceptance is not granted.

To update a stranger's acceptance, we also focus on relationships between the stranger and the owner. Here, social referencing is used to interpret the relationship between a stranger and a trusted person. Social referencing is the seeking of information from another trusted individual to form one's own understanding and guide action. Generally, social referencing can emerge as early as human infancy. However, social referencing has also been observed in dogs [8]. Therefore, acceptance updating is based on social referencing. In other words, updating is based on a non-owner's reaction when the exploring behavior is done solely from the robot's perspective. However, in reference to the owner's behaviors, the robot can include the non-owner's perspective when updating the acceptance of that person. Specifically, if the owner stays close to the trusted non-owner for a while, attachment to the non-owner likely increases.

From these two approaches, the degree of acceptance changes, and the relationship between the non-owner and the robot is updated. Thus, the robot's behaviors will vary based the level of acceptance toward these non-owners.

III. Experiment

A preliminary experiment was conducted to clarify subjects' impressions of a robot's behavior based on the improved Etho-engine. Additionally, even when using a modified Etho-engine, this system should still be recognized as involving attachment behaviors. If the robot properly showed attachment behaviors, we expected that the subject would be able to distinguish the owner from non-owners. Next, we designed an experiment and questionnaires for evaluating the improved robot behaviors, which were attachment behaviors and subjects' impressions of those behaviors.

A. Experimental set up

Each subject completed a questionnaire while watching a movie that was recorded using a simulator (see Fig. 1). There were three experimental movies, and each subject watched all three. In the test movies, there was a robot owner and another person in a room. The owner and the other person were able to play with a ball in the room. The experimenter operated the behaviors of the owner and the other person in the simulator. A simulated situation was used in order to show subjects the same interactions and remove any impressions toward the role-players.

Three experimental conditions were created. In condition 1, the degree of acceptance toward the non-owner was updated based on the proposed method. In this case, the initial acceptance value was 20 and was updated through various interactions. The degree of acceptance throughout the condition ranged from 0 to 100. In condition 2, the acceptance was 20 throughout the whole movie. In condition 3, the acceptance was 80 throughout the whole movie. The degree of attachment to the owner was 80 in in all 3 conditions. The robot's owner and the non-owner acted in the same manner in each condition. The movie scenario is as follows. First, the owner/non-owner enters the room, and then the other enters; both move around the room. Second, the owner/non-owner leaves the room, and then the other follows. This process was repeated four times during each movie. Interactions with the ball was added after the second entry/exit sequence. The sequence in which the owner and non-owner entered was different across the movies.

All of the movies were roughly three minutes long, presented at double speed. Each subject watched these movies in a random order and completed a questionnaire for each. Questionnaire content is shown in Table 4. Subjects reported on 5 domains regarding their impressions of the robot (1: not agree, 5: agree very much) and wrote open-ended descriptions regarding the reasons for their answers. The experiment was completed by 5 male and 5 female participants in their 20s.

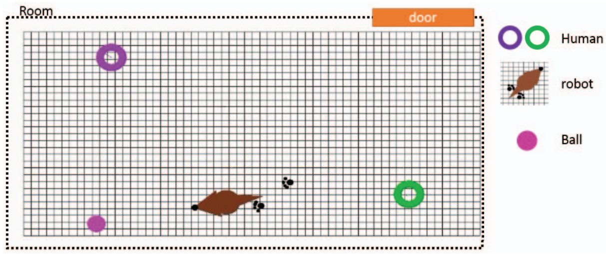

Fig. 1 Simulator setup

Table 4. Questionnaire content

Q1. Which person is the owner of the robot?
Q2. How do you think the robot feels about the other person?
Q3. Impression of the robot?

- Full of curiosity
- Affable
- Sociable
- Wariness
- Stiffly
- Faithfulness
- Friendly
- Quiet
- Timidity
- Independent
- Voluntary
- Smart
- Whim

B. Results

Results for Q1, "Which is the owner of the robot?" are shown in Table 5. Results for question Q2, "How do you think the robot feels about the other person?" are shown in Fig. 2 - 4. Subjects also freely described their answers. The answers can be classified into four groups: accepted, interested, afraid, not interested. Average values and variances for the impression scores are shown in Fig. 5. The number of robot behaviors during each movie is shown in Table 6.

Table 5. Correct answer rate for who is the owner

Acceptance of the stranger	Correct answer rate [%]
Updated (20 to high)	100
20	100
80	100

Table 6. Number of robot behaviors

Robot behaviors	Acceptance of the stranger		
	Change	Low	High
Go to the door	4	4	4
Greet the owner	4	4	4
Missing	5	3	8
Play with the owner	5	3	5
Explore the stranger	9	8	0
Go to the owner	3	6	0
Play with the stranger	1	0	3
Greet the stranger	1	0	3
Passive behavior	14	10	15
Owner playing	5	3	5
Stranger playing	2	4	3

IV. Discussion

First, we discuss results from Q1. All subjects recognized the owner across all experimental conditions, as shown in Table 5. This result suggests that robot attachment behaviors were easily determined, and acceptance toward the stranger could be correctly identified. In particular, we expected that some subjects might recognize the stranger as the robot's owner because the robot performed positive behaviors toward the stranger if acceptance toward the stranger was high. However, this prediction did no hold. Thus, our findings indicate that the enhanced Etho-engine could be adequately used for modeling attachment behavior.

Results for Q2 are shown in Fig. 2. Here, nearly all subjects noticed that the robot was displaying positive feelings toward the stranger when acceptance of the stranger was updated. This is in line with our hypotheses since acceptance of the stranger gradually increased; thus, the robot started to perform positive behaviors toward the stranger once acceptance exceeded a threshold. In this case, the robot and stranger engaged in positive interactions during the experiment. When acceptance of the stranger was fixed and low, several subjects expect the robot to "dislike" the stranger,

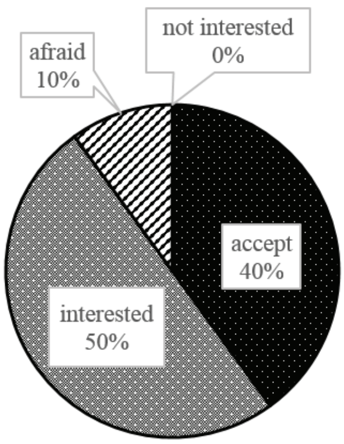

Fig. 2. Answer to Q2: Acceptance is updated

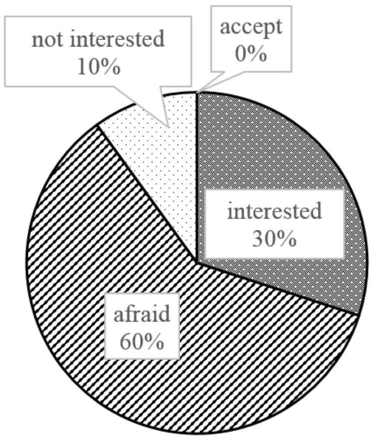

Fig. 3. Answer to Q2: Acceptance is 20.

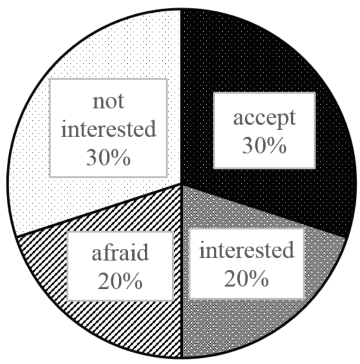

Fig. 4. Answer to Q2: Acceptance is 80.

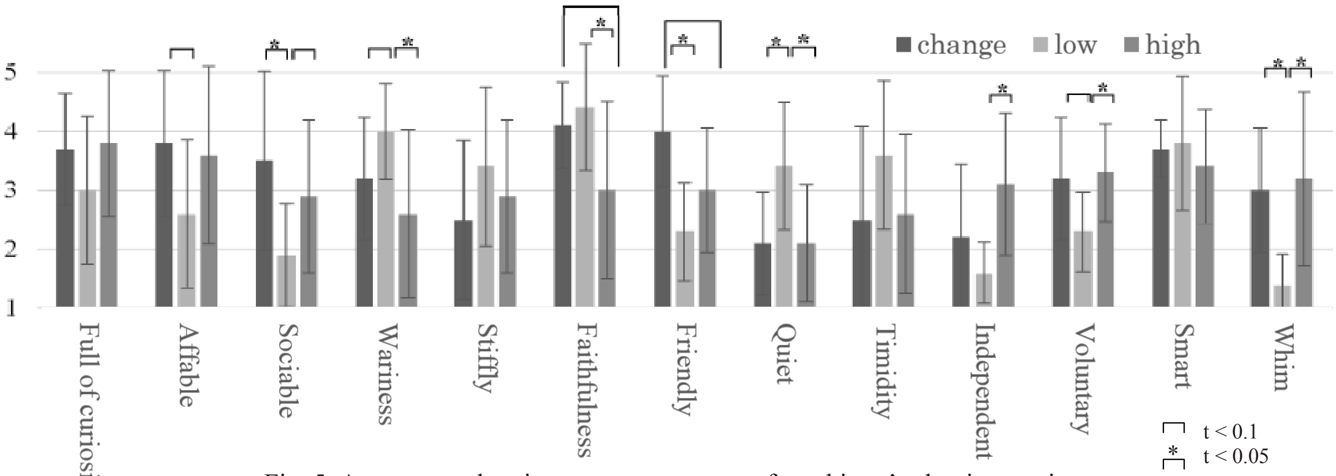

Fig. 5. Averages and variances among answers for subjects' robot impressions

even if the robot was engaging in exploring behaviors. Conversely, results from condition 3 were different from what was expected. Here, acceptance of the stranger is fixed and high. Therefore, it was expected that all subjects would answer similarly to answers given for condition 1. However, as shown in Fig. 4, the percentages are different. This might be due to so-called "passive" behaviors from the robot. Passive behaviors involve the robot moving to a secure place. When the acceptance of the stranger is high, inner states are often low. In turn, the Etho-engine has a high tendency toward selecting a passive behavior. It is likely that some subjects recognized this behavior as negative, whereby the robot was trying to escape the stranger or was losing interest (especially since this behavior was selected suddenly). The important findings regard the relationship between the robot and stranger being different across the experimental conditions, even if a tendency toward passive behavioral selection was the same. Therefore, subjects might have realized a change in the robot's behavioral tendency based on its interactions. From there, subjects could interpret the relationship between the robot and the stranger based on other situations.

We suggest that there are some particularly important impressions derived from our human-robot communication, including sociable, faithful friendly, and smart. First, it is important that the robot is sociable and friendly in order to promote interactions between the owner and non-owners. Second, it is necessary that the robot is faithful based on the attachment behavioral model. Additionally, it is preferable that the robot is sufficiently smart and cogent. We discuss results while focusing on these impressions below.

Averages for the "sociable" and "friendly" impressions in condition 1 are higher than what is observed in the other conditions (Fig. 5). We expected that positive interactions between the robot and stranger would be related to this result. However, the number of positive behaviors in condition 1 was lower than in condition 3 (Table 6). This result suggests that changes to the relationship between the robot and stranger were crucial for forming the subjects' "sociable" and "friendly" impressions rather than the number of positive interactions between the robot and stranger.

Averages for the "faithful" impressions in condition 2 are higher than what was observed in the other conditions (Fig. 5). We assume that the robot's negative behaviors toward the stranger gave off a faithful impression toward the subjects. However, the average for "faithful" in condition 1 was nearly the same as in condition 2. This result suggests that subjects maintained this "faithful" impression, even if acceptance of the stranger had changed, and the robot displayed positive behaviors toward a non-owner. From this, we could confirm that the enhanced Etho-engine was able to correctly demonstrate attachment behaviors.

An impression of the robot being "smart" did not differ across the conditions. Based on the open-ended descriptions, subjects appeared to view the robot as smart when presented with the robot's autonomous, selective behaviors. Therefore, the "smart" ratings in conditions 1 and 2 were higher than in condition 3, where the robot was friendly at the beginning of the movie.

Overall, we confirmed that the enhanced Etho-engine was able to properly display attachment behaviors in a social environment, which was not restricted by parameters of the original strange situation test. Nevertheless, to better highlight the developmental relationships between a robot and stranger, it is useful to provide holistic assessments of user-robot interactions.

V. Conclusion

To better address feelings of isolation experienced by some elderly adults, we proposed a long-term human-robot relationship that was inspired by human-dog interactions. In this study, we modified the attachment behavior model to suit an interaction that included a familiar person. Thus, we were able to improve upon the Etho-engine. Specifically, we are able to generalize a robot's inner states while also updating rules for these inner states. Additionally, we show that a robot can develop a preference for a person other than an owner.

However, when an actual robot is used for a real-life interaction with subjects, impressions may be different. Therefore, future work will need to assess actual human-robot interactions. Furthermore, while subjects evaluated impressions of the robot as a third party in this study, impressions will likely vary when a subject is actually interacting with a robot as an owner or stranger. Therefore, we will test examinations about it in the future. And after this study, we reconsider passive behavior to give a right impression.

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References

[1] Loneliness May Boost Odds of Dementia, "consumer.healthday.com/senior-citizen-information-31/misc-aging-news-10/loneliness-may-boost-odds-of-dementia-671433.html."

[2] SHIBATA TAKANORI, Therapeutic seal robot as biofeedback medical device, Proceeding of IEEE, Vol.100, 2527-2538, 2012.

[3] M. Kanoh, T. Shimizu, Developing a robot Babyloid that cannot do anything, Journal of the Robotics Society of Japan, Vol.9, No.3, 298-305, 2011.

[4] Á. Miklósi, R. Polgárdi, J. Topál, and V. Csányi, Intentional behavior in dog-human communication: An experimental analysis of 'showing' behavior in dog, Animal Cognition, Vol.3 No. 3, 159-166, 2000.

[5] J. Topál, Miklósi, V. Csányi, and A. Dóka, Attachment behavior in dogs (Canis familiaris): A new application of Ainsworth's (1969) Strange Situation test, Journal of Comparative Psychology, 112-3, 219-229.A, 1998

[6] M. Niitsuma, T. Ichikawa, R. Numakunai, A. Onodera, P. Korondi, H.Hashimoto, Design of social behavior of physical agent in intelligent space, in the Proc. of the 38th Annual Conference of the IEEE Industrial Electronics Society, 5507 - 5512, 2012.

[7] Takuya Ichikawa, Mina Yuki, Peter Korondi, Hideki Hashimoto, Marta Gacsi, and Mihoko Niitsuma, Impression evaluation for fifferent behavioral characteristics in ethologically inspired human-robot communication, in the Proc. of the 21st IEEE International Symposium on Robot and Human Interactive Communication, 55-60, 2012. 10 Sep., Paris, France.

[8] Merola · E. Prato-Previde · S. Marshall-Pescini, Social referencing in dog-owner dyads? Animal Cognition 15, 175-185, 2012