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Exploratoryl Behavior in Ethologically Inspired Robot Behavioral Model

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***Abstract*— This paper presents an exploratory behavioral model for human–robot communication based on an ethological approach. To maintain long-term human–robot communication, building social relationships between the user and robot is important. As a model of social relationships between different species, we focus on human–dog relationships. We apply dogs' behaviors observed from the stranger situation test as a base model of the robot. Exploratory behavior is one of the dogs' behaviors. In this paper, human–robot communication is considered for the purpose of home-care support. For this purpose, an exploratory behavior model for home-care applications is proposed.**

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

I. INTRODUCTION

Intelligent environments are being studied to support and enhance human activities. In some such studies, the subjects are observed using distributed networked sensors, human activities are observed, and services are provided using distributed actuators such as displays and mobile robots. To observe a 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 type of space an Intelligent Space (iSpace). A DIND, which is a basic iSpace element, consists of three basic components: sensors, processors, and network devices. Communicating with individual DINDs enables an iSpace to apprehend and understand events occurring within the space, and to activate intelligent agents such as mobile robots, computer devices, and digital equipment to provide information and services to users based on the observed information [1]-[4]. An iSpace can obtain the positions of more than one person at the same time, even if these persons are in different locations within the space.

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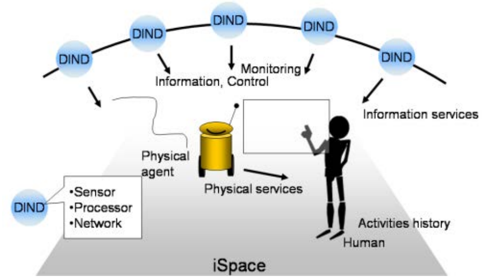


Figure 1. iSpace concept

A monitoring system is necessary to reduce the amount of attention and care required by care assistants and nurses for maintaining the safety of the elderly in their care. We therefore use iSpace to monitor a daily environment for the purpose of home-care support.

To apply iSpace to a support system for monitoring the elderly, after detecting an event in the environment, iSpace needs to inform the situation to the caregivers without disturbing their primary activities. Since a caregiver usually moves within a space, the information should be presentable at any location within this space. Mobility is required for a physical agent of iSpace. We therefore use a mobile robot to provide monitoring information to a care assistant.

Robots have been used to deliver information services to users within a wide range of applications, for example, daily information delivery [5], a cooking support system [6], and to guide robots in a museum [7]-[9]. A study on a cooking support system has suggested that robot behaviors are particularly useful for presenting location information to users. A robot is also useful in increasing the pleasure derived from cooking. The robot behaves on the basis of the user's cooking method. In the case of an information-delivery robot [5], the robot was evaluated through comparison with a computer display. The experiment showed that, compared to a display, users felt a sense of emotional attachment to the robot, and even attended to it. Accordingly, we consider robot behavior a useful and effective way to deliver information to users. A robot behavioral model, however, depends on the user applications.

When we consider a robot to be used continuously over a long period of time, relationship building between users and the robot becomes more important. A robot is required to behave appropriately to build social relationships with its users. The robot is also required to behave autonomously based on the current situation within the working space to present the monitoring results. We therefore need to consider a robot behavioral model that enables the robot to communicate with people and behave autonomously to reflect the situations of the environment. To address this issue, we proposed a robot behavioral model based on an ethologically inspired approach [10].

One feature of this ethological behavioral model is to show attachment to the owner by demonstrating behavioral differences between interactions with the owner and with a stranger. One of the key behaviors to show attachment to an owner is exploratory behavior. In the previous model, the behavior was simple random movement in a room. From the experimental results, we found that the subjects were unable to find any meaning in the robot's movement and did not recognize the movement as an exploration [11].

The exploratory behavior of dogs, however, is known to show exploration to the owner, strangers, and objects. We propose an improved exploratory behavioral model for robots to show a different frequency of target selection, and a different trajectory to reach target on the basis of such behavioral factors as the level of attachment to the owner and the acceptance of strangers.

The rest of this paper is organized as follows. Section 2 presents a robot behavioral model based on an ethological approach. Section 3 describes an improved exploratory behavioral model for a robot. Sections 4 and 5 detail the experiments used to evaluate the model. Finally, the last section provides some concluding remarks regarding the proposed model.

II. Ethologically Inspired Robot Behavior for Monitoring Support System

For the continual, long-term use of a robot without stress or loss of interest, social relationships between a user and the robot have become quite important. This relationship goes beyond the simple functionality of the robot. At the same time, the robot is required to show monitoring information to the users. To realize this, we focus on human–dog relationships [12]. A dog can behave according to not only its own situation but also to the situations surrounding it; in addition, people can interpret the dog's behaviors corresponding to the situation. If someone can interpret the dog's behavior, he or she can expect a corresponding situation. Importantly, dogs also show attachment to their owners. Dog behaviors are therefore suitable for use in a robot behavioral model to show both monitoring information and attachment to users.

Kovacs et al. presented an ethologically inspired human–robot interaction model to achieve a natural-like interaction between robots and humans [13]. The important aspect of this study is a proposed mathematical model based on a verbally described ethological model. The authors introduce state variables to describe the inner state of a dog according to the environmental context. The original model of dogs' behaviors was investigated on the basis of a "stranger situation test" [14]. In this test, a situation in which a dog is stressed by an unfamiliar environment and an unfamiliar person is considered. This model is appropriate for our model to show an attachment to users and stressful situations. We therefore applied this model as the basis of the robot behavioral model considering the owner as the caregiver and the stranger (unfamiliar person) as an elderly person under care.

The expected situation in the monitoring application, however, is slightly different from the original model, that is, a nursing environment where the people should be known and familiar to the robot. To deal with this, we add a tuning mechanism for the robot's behavioral characteristics based on the dogs' behavioral factors [14] in the previous model [12].

A. Inner states and robot behaviors

The proposed behavioral model has three inner states to reflect the situations occurring in the environment: miss, which represents the level of stress induced by separation from the owner; anxiety, which represents the level of stress induced by the elderly person's situation; and explore, which indicates the level of desire to look around the room. The inner states are updated on the basis of the observations by iSpace [12]. Details of the observation function of iSpace and an elderly person's situation to be detected are presented in [10]. An appropriate robot behavior is then selected from the behavioral set. The rule of selection and the behavioral set are defined according to scientific knowledge of the social behavior of dogs [13, 14].

To distinguish robot behaviors from genuine dogs' behaviors, behavior codes are expressed using "RDog." Table I shows the robot's behavioral set based on a "stranger situation test," and leading behavior observed from a "hidden food test" [15]. In the monitoring support system, we assign the dog's owner in the original model to a caregiver who provides home care (person C), and an unfamiliar person to an elderly person who is a care receiver (person E).

TABLE I. Behavioral Set

	Behavior label	Behavior
Attachment behaviors	RDogExplores	Exploring a room
	RDogPlaysWithPerson	Playing with a person
	RDogGoesToDoor	Standing at the door in the absence of person C
	RDogGreetsPersonC	Greeting person C
	RDogGoesToPersonC	Standing by the side of person C
	RDogPassiveBehavior	Standing or sitting down around a safe place
Leading behaviors	RDogGetsAttention	Getting the attention of person C
	RDogShowsDirectionalSignal	Showing the direction toward a target place

The behavioral set and inner states are recognized as the base model of the robot behavior for the monitoring support system. To apply the model to the monitoring support system, we modify the update rule for the level of explore. In the original ethological model, the level of explore is caused by stress from an unfamiliar environment. Therefore, exploratory behavior might be observed just after entering the room in the presence of the owner.

In the monitoring system, the robot should be familiar with the environment. The robot is required to show the owner an exploratory behavior to present the safety of the situation within the room. From this, the level of *explore* is given such that the exploratory behavior is performed on a regular schedule. Note that the observation of the space is carried out by iSpace. Therefore, the robot can move within the space independently from the observation.

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

B. *Implementation of robot behaviors*

The robot behaviors enumerated in Table I are implemented. The robot hardware consists of an emotional expression part and a mobile platform [12]. We used a Pioneer P3-DX as the mobile platform. For the mobile platform, a suitable goal position of the movement and velocity for each behavior should be given. Using the head part, the robot expresses not only each behavior but also the inner states based on the level of the parameters, *miss*, *anxiety*, and *explore*.

The movement of the mobile platform for each robot behavior is described as follows.

a) RDogExplores: The robot explores the room. In the previous model, a goal is given one point in the region shown in Fig. 2. Section IV describes the details of this improvement.

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 a robot, we implement this behavior as "playing with a person and a ball." The robot follows a yellow ball using a color camera, and then brings the ball to the person. This behavior is exhibited when the person is sitting down to start playing with the robot.

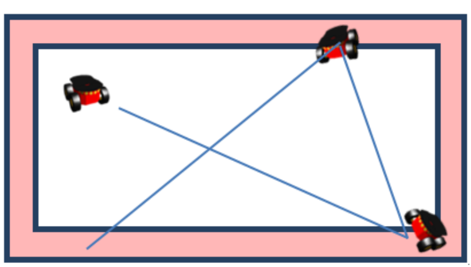


Figure 2. Region within which the location of the goal is set for "RDogExploresRoom"

c) RDogGoesToDoor: The robot goes to the door and stays there. The location of the door is given in advance.

d) RDogGreetsPersonC: The robot follows person C (caregiver) gleefully. The location of the goal for the movement is updated as the current location of person C.

e) RDogGoesToPersonC: The robot comes close to Person C and stays nearby.

f) RDogGetsAttention/RDogShowsDirectionalSignal: This leading behavior consists of two actions. First, the robot tries to get person C's attention, and to do so, it comes close to and stands in front of person C. Next, the robot attempts to go to the goal location with person C. If person C does not move toward the goal with the robot, the robot stops and shows the person the direction of the goal by rotating its body, turning its head toward the person until the person starts to move.

III. Improvement of Exploratory Behavior

A. *Exploratory behavioral model based on dogs' behaviors*

As exploratory behavior, the targets for exploration are known to be selected by the owner and a stranger in the original ethological model. In addition to these two targets, we need to consider the places and objects for exploration in the monitoring support system to detect unsafe situations.

To build a model of exploratory behavior, we consider three targets to be explored as destinations of the robot movement: the caregiver, an elderly person, and a location. The exploratory behaviors for each target are called "explore owner (EXPO)" and "explore stranger (EXPS)" [15]. When the robot selects an open place as a target, we distinguish this behavior from the above two exploratory behaviors, which is called "explore place (EXPP)."

After a target is selected, a destination is chosen around the target. The probability of each target for exploring a selection depends on the behavioral characteristics of each dog. The path to a target also varies among different individuals. For example, a dog that expresses high attachment to its owner tends to select EXPO. A timid dog tends to move to avoid strangers.

The robot's behavioral characteristic for an exploratory behavior is defined based on dogs' behavioral factors: level of *attachment to the owner* and level of *acceptance of strangers*. The levels of each behavioral factor are given a value from 0 to 100. The targets to be explored are selected on the basis of these behavioral factors.

B. *Implementation of model for exploratory behavior*

The proposed exploratory behavioral model consists of three processes: a) a description of the movement history of the robot and willingness to explore an environmental map, b) selection of a target for exploring, and c) generation of a path and movement toward the target. We use a grid map for the environment map, as shown in Fig.

3. Each cell is given values to express the movement history of the robot and willingness to explore. These values are used for calculating the probability of the target selection and path planning. The map also shows the location of the persons and base station of the robot.

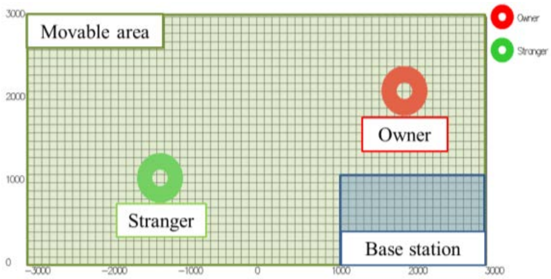


Figure 3. Grid map

a) Describe the movement history of the robot and willingness to explore an environmental map: The robot comes close to person C and stays in the person's vicinity.

The value of the movement history at each cell represents the level of movement frequency. Another value showing the willingness to explore represents the level of easiness to reach the cell. The value of movement history, $h_{ij}(n+1)$, at cell (i, j) at time n is set as follows:

$$\begin{cases} h_{ij}(n+1) = h_{ij}(n) + \mu, & \text{if the robot is at cell } (i, j). \\ h_{ij}(n+1) = h_{ij}(n) - \lambda, & \text{else if a moving object is at cell } (i, j). \\ h_{ij}(n+1) = h_{ij}(n) - \phi, & \text{otherwise.} \end{cases} \quad (1)$$

Here, μ and λ are positive constant values. We consider that the place where objects move is to be explored. Therefore, λ is given a greater value than μ. To refresh the movement history, we consider a forgetting factor of the movement history φ. φ is subtracted from each value of movement history. φ is set to reduce h_{ij} to zero if the robot does not pass through the area within 2 min. When h_{ij} is greater than 0.5, the area is recognized as a known area; otherwise, the area is unknown. The values are used to select a destination in an unknown area when EXPP is selected.

To detect other objects, we use UTM-30LX laser range finders (Hokuyo Automatic Co., Ltd.) and extract moving objects using an inter-frame differential based method [16].

The values of willingness to explore at a cell are explained next. These values are used to choose a destination and determine a path. Values of willingness to explore the caregiver and the elderly, from –1.0 to 1.0, are given to each cell based on the location of the persons and each behavioral factor. Specifically, the value of willingness to explore the caregiver in cell (i, j) is given by P_{cij}. P_{cij} is calculated using the degree of *attachment to owner* D_o, and the distance between the caregiver's position and the cell (i, j), d_{ij}. The baselines of the behavioral factors are set as 50, and positive and negative willingness is expressed based on these baselines; for example, a value smaller than 50 indicates a negative willingness to explore.

$$P_{cij} = \frac{D_o - 50}{50} e^{\alpha d_{ij}} \quad (2)$$

Where α is a constant scaling factor. The value of α is experimentally determined.

The value of willingness to explore the elderly P_{eij}, is defined in the same way. Finally, the value of willingness to explore cell (i, j), P_{ij}, is obtained by (3).

$$P_{ij} = P_{cij} + P_{eij} \quad (3)$$

Fig. 4 shows a grid map with willingness to explore added. The color intensities represent the values of the willingness to explore. Orange shows positive willingness and blue shows negative willingness. White indicates moderate willingness.

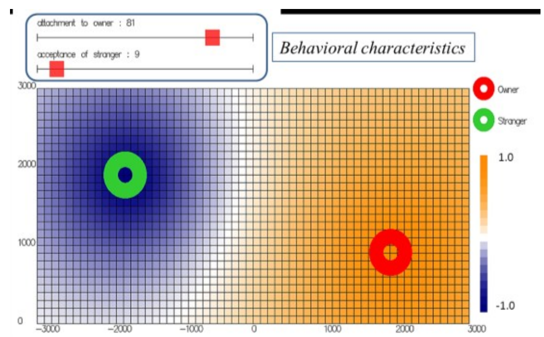


Figure 4. Grid map with added willingness to explore

b) Selection of target for exploring: A target to explore is selected stochastically on the basis of behavioral factors, the movement history of the robot, and its willingness to explore. The possibility of each person being selected is proportional to the behavioral factor. Thus, when an attachment to an owner is given a high value, the possibility of an EXPO selection becomes high. For EXPP, the possibility of an EXPO selection is proportional to the number of unknown areas in which the willingness to explore is over –0.3. Otherwise, a passive behavior is selected.

c) Path determination to target for exploring: To express an exploratory behavior as an attachment behavior, the expression of the differences among easiness to approach a target values is important. The differences should be expressed through the paths used to reach the targets. Therefore, the path to a target for exploring is generated on the basis of the behavioral factors.

We apply a potential field method with a grid map to path determination. The willingness to explore is regarded as a potential field. Specifically, a path is determined by assuming that areas with low willingness to explore values generate repulsive forces, while the target for exploring generates attractive force acting on the robot. Therefore, according to (2), the robot moves by avoiding a person whose behavioral factor is at a low level. In the potential field method, input vector V is defined by (4).

$$\mathbf{V} = \mathbf{V}_{at} + \mathbf{V}_{rep} \quad (4)$$

Where $\mathbf{V}_{at}$ is an attraction vector and $\mathbf{V}_{rep}$ is a repulsive vector. $\mathbf{V}_{rep}$ is given by (5).

$$\mathbf{V}_{rep} = \beta \cdot (P_{\max} - P_{\min}) \cdot P_R \cdot \mathbf{v}_{rep} \quad (5)$$

Where β is a scaling factor to determine influence rate between the attractive force and the repulsive force, P_R is the willingness to explore the area at the robot's current position, and $\mathbf{v}_{rep}$ is a repulsive unit vector indicating the direction from the location with the highest value of willingness to the location with the lowest value of willingness within the 8 neighboring areas around the robot's location, as shown in Fig. 5.

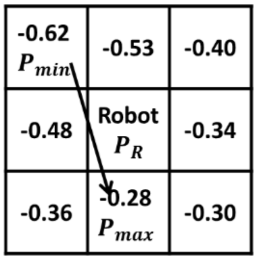


Figure 5. Direction of repulsive unit vector

IV. Experiment for Behavior Evaluation

A. Setup

We conducted an experiment to confirm the robot's behavior by means of the robot's pathway when the behavioral factor levels change. Table II summarizes the setup of the behavioral factors used in this experiment. To determine a person's fixed location in each case the experiment was carried out using a simulator. In each case, the robot explores in the room for 1 minute. Design parameters $\alpha = 0.75$, $\beta = 1.10$, $\mu = 0.06$, $\lambda = 0.15$, $\varphi = 0.02$ are given.

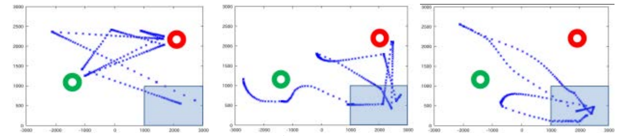
TABLE II. Parameter Settings for Three Cases

	Attachment to owner	*Acceptance of stranger*
case A	90	90
case B	90	10
case C	10	10

B. Experimental Results and Discussion

Figure 6. shows the robot's trajectories in each case. Red and green circles represent the caregiver and the elderly person. Blue dotted lines shows the robot's trajectories. Table III presents the average number of times per minute that the robot selects a target to explore. In case A, we found that the robot moved along straight-line trajectories in Fig. 6 (a). From this trajectory, the robot can select any targets anywhere in the room. The stranger was selected as a target as many as the owner In case B in Fig. 6 (b), we found that the robot walked away from the stranger, but tended to approach the owner. Thus, the owner was selected more often than the stranger. In case C in Fig. 6 (c), the robot kept away from both persons. The area within which the robot could move was very narrow. The robot tended to select passive behavior.

We confirmed that the target for exploring was selected stochastically on the basis of the behavioral factors, and the robot could change paths according to the behavioral characteristics.



(a) Case A (b) Case B (c) Case C

Figure 6. Simulator path in each case

TABLE III. Number of Times each Target was Selected

	Case A	Case B	Case C
EXPO [%]	34.6	42.2	9.8
EXPS [%]	32.7	8.9	7.3
EXPP [%]	21.2	17.8	26.8
Passive [%]	11.5	31.1	56.1

V. Experiment for Impression Measurement

The behavioral characteristics of the robot are given using the behavioral factors. What is important here is whether the behaviors can fit a person's expected impression, and we conducted an experiment to confirm this using an actual robot. The robot behaviors for three different characteristics were captured on video. Subjects gave their impressions of robot behaviors while viewing the three different videos. The sets of characteristics for the three cases are listed in Table II. The experiment was conducted in a room without a dividing wall. The owner, stranger, and robot were in the room, and the owner and stranger could move freely.

Adjective keywords from the questionnaire used to evaluate the subjects' impressions are listed in Table IV. We selected the keywords by referring to words used to express the characteristics of a dog. The subjects gave their level of impression using a five-grade evaluation, where four was the highest score (most appropriate), and zero the lowest score (least appropriate).

TABLE IV. Impression Keywords for Experiment 2

Impression keywords	
Curious	Faithful
Friendly	Timid
Cautious	Arbitrary

In case A, since the behavioral characteristic parameters are high, we expected that the impression keywords "curious," "friendly," and "arbitrary" would have a high score. In case B, since *attachment to owner* is higher than *acceptance of strangers*, we expected that the impression keywords "cautious," "faithful" and "timid" would have a high score. In case C, since the behavioral characteristic parameters are low, "timid" would receive a high score.

A. Setup

Ten subjects, each in their 20s (all male), participated in the experiment. The subjects viewed the all videos for cases A, B, and C before the experiment. At this time, they were not given any information, except which person in the video is the owner of the robot. The subjects were then divided into three groups, with each group watching a different video. After viewing all videos in turn, the subjects answered the questionnaire. Here, we required the subjects to give clear reasons for answering each question if possible.

B. Experimental Results and Discussion

Fig. 7 shows the average score for each impression keyword. Error bar represents standard deviation.

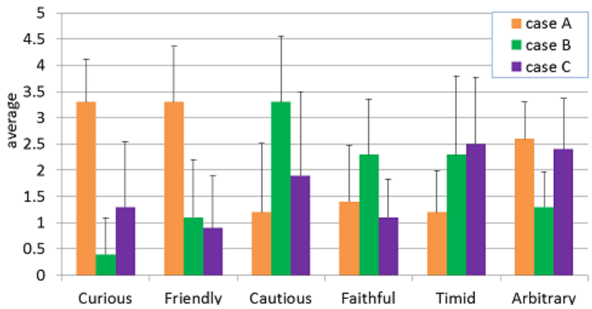


Figure 7. Experimental results (impression measurement)

In case A, "curious," "friendly," and "arbitrary" received high scores compared with the other cases. In case B, "cautious" and "faithful" received high scores. Finally, in case C, "timid" and "arbitrary" received high scores.

In this experiment, the subjects did not have any information regarding the differences in the robot's behavioral characteristics. Through the experimental results, as expected, we confirmed that the subjects had an impression of the robot behaviors in each case. We further confirmed that the behavioral characteristics could be given by the behavioral factors, as expressed by the exploratory behavior, and that the subjects could perceive the differences without any knowledge about the robot behaviors.

As the exploratory behavior used in the monitoring support system, the differences in behavior toward the owner and the stranger is important. Therefore, it is necessary for the robot to be able to give "faithful" and "cautious" impressions when appropriate. To realize this, we use the parameter setup in case B as a base model. Elderly persons, however, should be recognized as familiar persons even if they are not the robot's owner. We define a stranger as an unfamiliar person distinguishable from an elderly person, and define an elderly person as a familiar person, given a high value of *acceptance of strangers*, which is a basis used to distinguish between strangers and familiar persons.

In this experiment we gave distinguishing values to *attachment to owner* and *acceptance of strangers* to compare behavioral characteristics among different set of the behavioral factors. To apply the robot to long-term interaction, the behavioral factors should be tuned to adapt user's preferences and experiences in the interaction.

VI. Conclusion

This paper presented an exploratory behavioral model for a robot based on the ethological behavior of dogs. This model selects a target for exploring and generates a path to reach the target based on the robot's behavioral characteristics. To realize this, we proposed a map-building method to describe not only the location of persons and the robot but also the robot's movement history and willingness to explore, taking behavioral factors into consideration. From the experiments, we confirmed that the subjects were able to feel different impressions from the proposed exploratory behaviors.

As future work, we will integrate exploratory behaviors with the base model for a monitoring support system.

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