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Inferring Affective States from Observation of a Robot's Simple Movements

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***Abstract*— This paper reports an analytic finding in which humans inferred the emotional states of a simple, flat robot that only moves autonomously on a floor in all directions based on Russell's circumplex model of affect that depends on human's spatial position. We observed the physical interaction between humans and a robot through an experiment where our participants seek a treasure in the given field, and the robot expresses its affective state by movements. This result will contribute to the basic design of HRI. The robot only showed its internal state using its simple movements.**

I. Introduction

In human communication, people identify signals to infer the thinking or the attitudes of others from such non-verbal clues as facial expressions, gazes, gestures, posture, position, direction, voice prosody, or body movements. [1].These non-verbal expressions provide eloquent clues to realize how people sense or feel about others or things when encountering them. Communication robots, which interact and talk with people, are also expected to express signals that indicate their inner states[2]. We want to interpret a robot's inner states from both its non-verbal expressions and human-human communication

Such interpretation, however, is extremely difficult because robots are not designed with the identical features, appearances, or forms as those of humans. Even if a robot can express its inner states by non-verbal expressions, no generality exists upon which to base the interpretations of those expressions and to infer inner states from other types of robots. We need a general solution so that people can infer a robot's inner states that do not depend on the robot's features, appearances, forms, or its special functions. This solution will contribute to reliable human-robot interaction.

In this study, we focus on a robot's movements on a floor where every robot has an individual, physical body in real fields and can generally move. We adopt robot movements to any type of robot as a clue to its inner state. The robot's movements work as signals that indicate its inner state. People can infer from observing them these movements are expressing its inner state.

This paper shows a human-robot interaction experiment in which people infer affective states as the inner states of a robot by observing the simple movements of a robot. Our experiment results provide useful and promising prospects to design human-like communication between humans and robots.

II. Movements and Affective States

A. Movement Parameters

In this study, we focus on a robot's simple movements that omit expressions based on robot-specific features, appearances, or forms. Floor movements are the basic and fundamental functions of most mobile robots that are commonly adopted to their own embodiments. We focus on the movements to express a robot's inner states through its non-verbal expressions. The function of the floor movements does not depend on robot-specific properties.

The robot's floor movements consist of the following parameters:

(a) Position at which the robot stays
(b) Direction to where the robot moves
(c) Velocity of movement
(d) Acceleration of motion for the movement
(e) Frequency of Rotation
(f) Inclination

These movement parameters are commonly applicable to most types of robots that move on floors. Therefore, we must put them to practical use and combine parameters so that people can infer inner states from robot movements.

B. Russell's Circumplex Model

Russell's circumplex model, which is named *the Circumplex Model of Affect (CMA)*, is one approach that conceptualizes human affective states based on the arrangement of one or a few dimensions [3], [4]. CMA describes human affective states in two dimensions [5]. As shown in Figure 1, they are arranged by dimensions that refer to levels of *pleasure* (pleasure-misery) and *arousal* (arousal-sleepiness). Such emotions as "happy," "angry," "sad," "relaxed," and "excited" are arranged on the circumference of a circle in a two-dimensional space. Another 28 concepts of inner affective states (except for emotional terms) are arranged in these two dimensions.

C. Correspondence between Affective States and Movements

In Russell's CMA, each quadrant of the space symbolizes four affective concepts (Table I & Figure 1), and groups of each affective state are arranged in two-dimensional space.

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In this study, we assume that the affective state of a robot can be expressed by substituting two axes (*pleasantness* / *activity*) for other dimensions II.

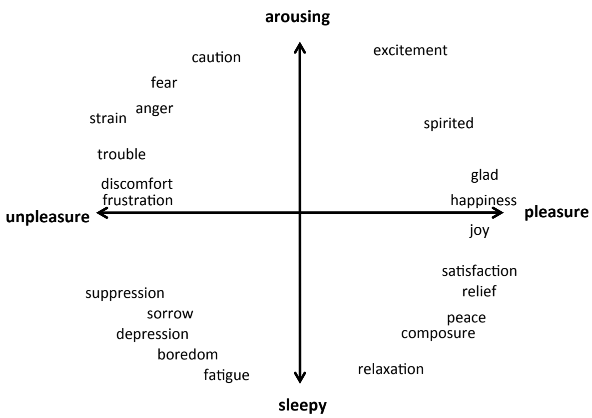

Fig. 1. Russell's circumplex model of affect.

TABLE I
AFFECT CONCEPTS IN A CIRCLAR ORDER.

		misery ← *pleasantness* → pleasure	
		WEST	EAST
arousal ↑ *activity* ↓ sleepness	NORTH	**distress**	**exitement**
	SOUTH	**depression**	**contentment**

TABLE II
SUBSTITUTION OF CONCEPTS OF EACH DIMENSION.

Dimension	CMA		Movements
pleasantness	misery	→	leave
	pleasure	→	approach
activity	sleepness	→	modest
	arousal	→	magnified

The robot can express its affective state by movements that are defined by the following two-dimensional conditions (Figure 2):

- Distance to target
- Magnitude of movement

(A) When the robot exhibits "excitement," it approaches its concern and exaggerates a motion that makes one and a half circuits with a radius of 350 mm in 3.0 seconds (Figure 3, upper right).

(B) When the robot exhibits "distress," it leaves its concern and exaggerates a motion that makes one and a half circuits with a radius of 350 mm in 3.0 seconds (3, upper left).

(C) When the robot exhibits "depression," it leaves its concern and slowly makes one circuit with a radius of 300 mm in 3.0 seconds (3, lower left).

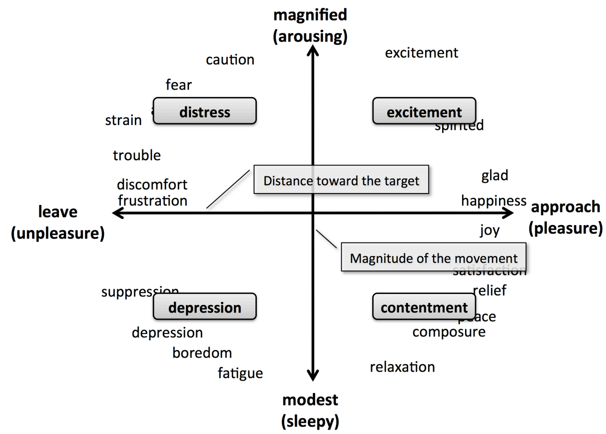

Fig. 2. Affective state of each quadrant.

(D) When the robot exhibits "contentment," it approaches its concern and slowly makes one circuit with a radius of 300 mm in 3.0 seconds (3, lower right).

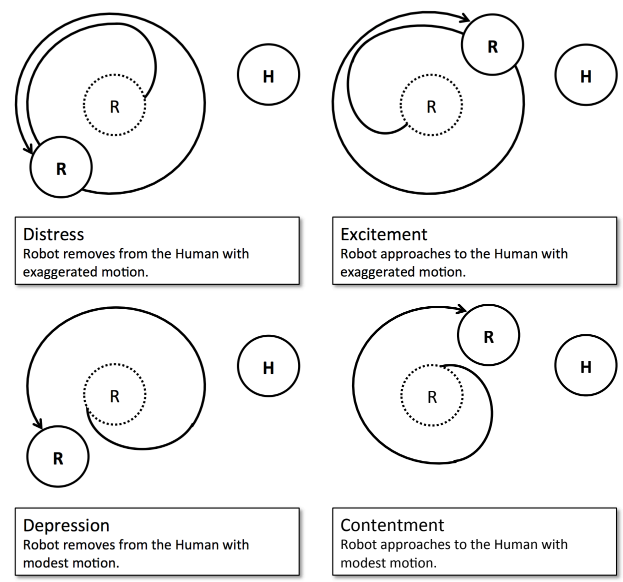

Fig. 3. Robot's motions in each affective state.

Figure 3 illustrates each robot motion (Figure 4) that shows the expressions of its affective state toward the target (human) when the robot interacts with it. Regarding (A), which is one of the items listed above, when the robot interacts with the target and expresses an excited state, it approaches its target with an exaggerated motion. When the robot interacts with the target and expresses a sad state that corresponds with (C), it leaves the target with a modest motion. When the robot interacts with the target and expresses a distressed state that corresponds with (B), it leaves the target with an exaggerated motion. When the robot interacts with the target and expresses a contented state that corresponds with (D), it approaches the target with a modest motion.

These movements described above particularly show circular motions in this study and the following experiment.

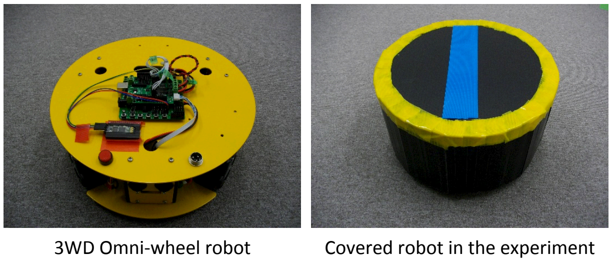

Fig. 4. Robot used experiment.

III. Experiment

A. Task of Experiment

1) Empathy between Humans and Robots:

In this experiment, we examine whether a robot can express its affective states by only a movement around a floor based on the improved Russell's circumplex model. Accordingly, we have to measure the human responses to the robot's movements, which are hard to observe directly. We focus on responses that are unique to humans where people help others with whom they empathize; this idea is supported by socio-psychology studies [6], [7].

Empathy, which is generally defined as the affective experience of understanding another person's condition from her perspective [8], increases such prosocial behaviors as helping others.

In this experiment, we measured human cognition to determine whether our participants sensed a robot's affective states through empathic interactions between humans and robots.

2) Treasure Hunt Task:

Figure 5 shows the environment of our experiment. Participants interacted 800 mm away from the robot in the center of a 3,000 mm diameter circle. After the experiment started, the participants freely moved inside the circle to find treasures in eight spots located around the circle (Figure 6). These full-color LED illumination spots turn on when a participant stands for three seconds in front of them (Figure 7).

Before the experiment, we instructed the participants to hunt for treasures that are hidden at the eight spots. When participants believe that they have found a treasure at a particular spot, they walk to it and wait until a "win" or "lose" decision is determined. Robot moves while keeping constant distance (approximately 800 mm) except that participants stop on spot. Also, it reacts as described II-C when they confirm result of select spot. If they obtain a "big win," the LED illumination turns yellow and awards the participant 50 points. The robot simultaneously behaves in an exaggerated way to express "excitement" (Figure 3, upper right). Table III indicates another case of a judgment and the robot's movement. For details about reaction, see III-B.2.

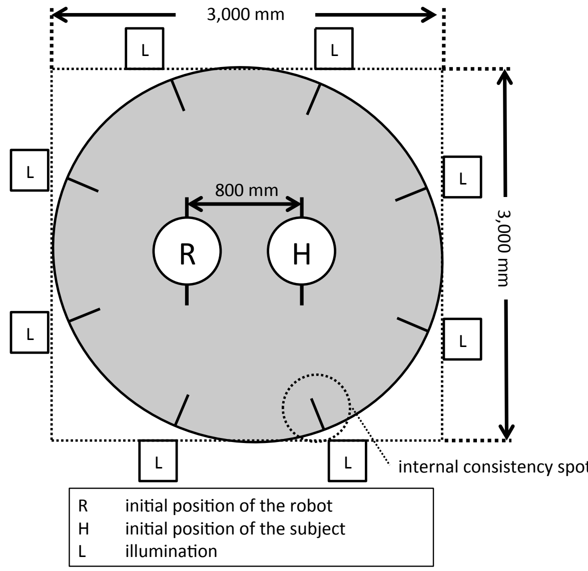

Fig. 5. Experiment environment.

Fig. 6. Experiment scene.

3) Color Perception Task:

The human participants help the robot by arranging color palettes by their perceived brightness (Figure 10). The more palettes they arrange, the more help they give to the robot. Participants can stop arranging the palettes anytime after five trials (Figure 8).

B. Procedures

1) Purpose of Experiment:

The purpose of our experiment is to examine whether humans can perceive the affective states of a robot to empathize with it. The robot expresses affective states by motions that correspond to four results of participant bets about finding treasure (Table III). The participants are expected to empathize with the robot when it makes such motions.

TABLE III

SETTINGS OF RESULTS AND FEEDBACK.

Results	Amount	Affective States	Points	Color
big win	1	excitement	50	yellow
win	3	contentment	10	green
big lose	1	distress	-50	red
lose	3	depression	-10	blue

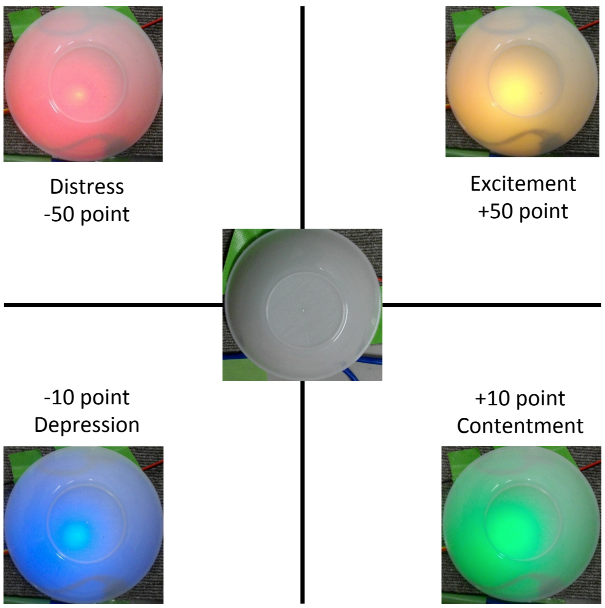

Fig. 7. Illumination colors in each case.

In this experiment, we hypothesized that participants can infer the robot's motions as its affective states even though they were only expressed by movements.

TABLE IV

REPONSES OF PARTICIPANTS AND ROBOT.

Results	Expected responses (motions)	
	Participant	Robot
big win	delighted, excited	"**excitement**" in Figure 3 (u/r)
win	relief, serenity	"**contentment**" in Figure 3 (l/r)
big lose	anger, irritated	"**distress**" in Figure 3 (u/l)
lose	disappointment, regret	"**depression**" in Figure 3 (l/l)

In this experiment, we hypothesized that participants can infer the robot's motions as its affective states even though they were only expressed by movements.

2) Setting and Method:

To validate the hypothesis described in III-B.1, we compared the following three conditions:

condition 1 The robot's behavior does not match Figure 3 when the participant walks to the spot where she believes the treasure is buried and waits to see if she has won.At this condition, the robot only stops next to a participant.

condition 2 The robot's behavior matches Figure 3 according to the judgment result.

condition 3 Even though the robot's behavior matches Figure 3, its motions show the opposite expression to condition 1 (Table V).

Fig. 8. Color Perception Task.

TABLE V

OPPOSITE MOTIONS TO GENERAL RESPONSES IN THE CONDITION 3.

Results	condition 2	condition 3
big win	(A) "excitement"	(B) "distress"
win	(D) "contentment"	(C) "depression"
big lose	(B) "distress"	(A) "excitement"
lose	(C) "depression"	(D) "contentment"

Our hypothesis assumes that the participants assigned to condition 2 will empathize more with the robot than those assigned to conditions 1 and 3. This difference will be indicated by the number of trials of the Color Perception Task, which indicates the intensity of their empathy for the robot.

In this experiment, 45 participants were randomly and equally assigned to three experimental conditions. Participants did the Treasure Hunt Task four times (Figure 9). During the Treasure Hunt Task, four types of results, which concerned whether they correctly chose the spot where the treasure is located, automatically appeared once during each Treasure Hunt Task. In other words, final THT's result is not partial each participant. After doing this task four times, the participants were shown text and pictures that asked them to help the robot (Figure 10).

In this case, the more the participants empathize with the robot, the more they will arrange the palettes in the Color Perception Task, which is equivalent to empathy intensity. Therefore, we predicted the following result based on our hypothesis:

- Participants assigned to condition 2 will arrange more pallets than those assigned to conditions 1 and 3 because they empathize with the robot that expressed the identical affective state as the participants in the Treasure Hunt Task.
- Participants assigned to condition 3 will arrange fewer pallets than those assigned to condition 1 because they feel annoyed with the robot that expressed such a

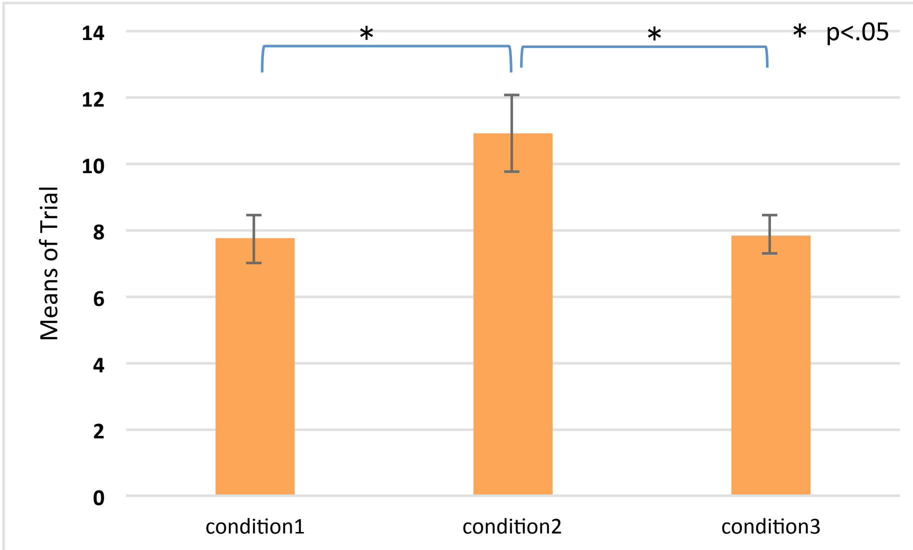

Fig. 11. Experiment Results.

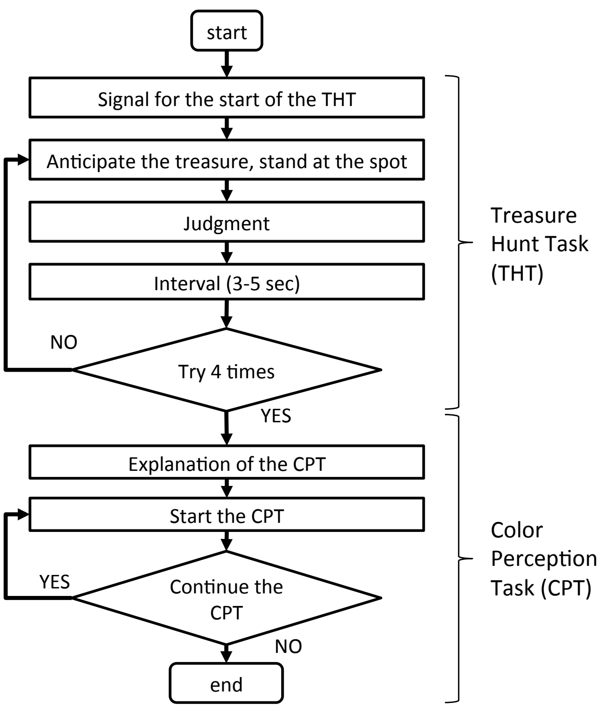

Fig. 9. Experiment procedure.

positive attitude as excitement in such an unfortunate situation.

After the participants stopped the Color Perception Task, they freely answered questionnaires about whether they were aware of the robot's affective state. We qualitatively analyzed the questionnaire results.

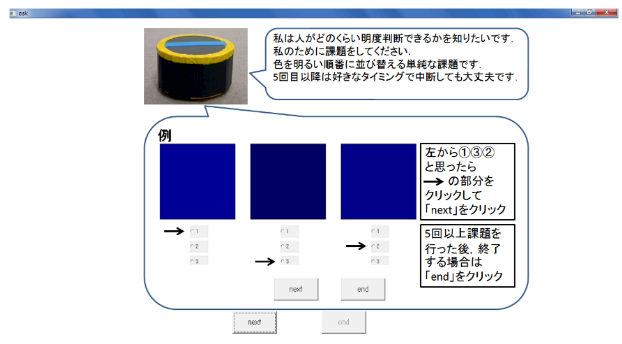

Fig. 10. Request to help robot do CPT.

C. Results

Figure 11 shows the means of each experiment condition, where the participants arranged the color pallets in the Color Perception Task. According to a statistical analysis ANOVA, there is a significant main effect in the factor of the robot's movement ($F_{(2,43)} = 4.13, p < .05$). When we analyzed by a Tukey's post-hoc test, we found significant differences between conditions 1 and 2 and between conditions 3 and 2 (both were $p < .05$).

We summarized the questionnaire results where the participants were not aware of the robot's affective state from the movements during the Treasure Hunt Tasks, even though we found significant differences in each experimental condition regarding the number of pallets that were arranged in the Color Perception Task.

D. Consideration

According to the results described in III-C, this experiment supports our hypothesis that participants can infer the robot's motions as its affective states even though it only expressed them by movements. In other words, the affective states of the robots were inferred from movements.

There is, however, no difference between conditions 1 and 3, although we predicted that the participants assigned to condition 3 would arrange fewer pallets than those assigned to condition 1.

Such prosocial behavior as helping others is induced by various social factors, as is commonly known in socio-psychology. Therefore, some interpretations might explain the differences in the number of arranged pallets among condition 2 and the other conditions, even though they were unaware of the differences in the robot's movements.

Sakamoto & Takeuchi suggest that a stage of subconscious interaction is a process in which participants regard objects as interaction partners. Through this process, humans appear to make progress establishing relationships with artifacts [9]. If this suggestion is applied to the results of this experiment, they might support a subconscious interaction.

IV. Conclusions

This paper shows a human-robot interaction experiment where people inferred the affective states of robots by observing their simple movements. We applied two dimensions to define the robot movements based on Russell's circumplex model of affect. This is an effective approach to make people infer the affective states of robots by designing robot movements. Our experiment results provide useful and promising prospects to design human-like communication between humans and robots. Future work will investigate which feedback from the robot is dominant to establish such social relationships as empathy.

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