Social Trash Box Robot: Behavior Parsing and Goal Inferences in Dynamic Interactions

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Abstract: It is necessary for a human-depended robot to convey its intention to elicit the assistance of humans in a dynamic environment, and the effectiveness of behaviors highly regulates the successes or failure of its goal. In addition, a robot can execute and switch desirable behaviors in dynamic interactions which depend on the precise distance between the interactive person and the robot, which is very important for a social trash box robot to collect the trash. Our work aims to centralize the robot's personal space for a social trash box (STB) robot to explore desirable or optimum behaviors and to establish trust in social interaction with humans, as well as how to determine how these behaviors are able to convey its intention or goal within each space. Our investigation is directed to explore (1) suitable behaviors which can convey STB intention from "asking help" and "not-asking help," and (2) what are the most optimum STB behaviors in each space to convey its intention in dynamic interactions.

1 Introduction

As is commonly known, humans regulate their interactions according to different contexts, the degree of the relationship, cultural factors, gender, age, etc [3]. These interactive manners show that humans are experts in social interaction and can distinguish a variety of behavioral patterns by personalizing their communicate partner [16][10]. Consequently, humans follow a different kind of social norm (approaching the interactions and move-away from the interaction) by consorting with their partner's negative/positive behaviors in the dynamic environment [1].

Socially atuned robots require a board range of the above social norms to establish interactions with humans [14]. Such robots must be adequate to detect and inference human behaviors and be able to align and collaborate with their behaviors in dynamic interactions. Many of the existing research approaches that have introduced human detection and behaviors inferences algorithms in human-robot interactions have had somewhat worthwhile outcomes in a variety of contexts [7][6]. At present, studies in social robotics are motivated by approaches that have been proposed to align/collaborate a robot's behaviors (e.g., conversation, body-gestures, etc.) according to a human's behavioral channels (e.g., eye-gaze) in different contexts [8][9][19][13]. Okada et al [12] proposed Talking-in-interaction by developing a novel robotics platform (Talking-Ally) which is capable of constructing the utterance (using turn-initial and entrust behaviors) based on the user's attention behaviors in dynamic interactions. The proposed approach was inspired by the way in which humans construct their utterances based on the behavioral variation of the partner, since we have to build up the principle, rules, and patterns of social norms for social robotics by following the manner in which humans interact with other humans.

Figure 1: Appearance of STB.

Our argument is that a socially aware robot requires an embedded approach that is capable of continually interacting with humans in a dynamic environment. But how should we integrate these functionalities? We believe that the moving behaviors of robot can be considered as one of the essential factors in establishing interaction with a human, which is mostly necessary in dynamic interactions for continued interactions [2]. However, during this interaction, the social robot should be capable of empathizing with how to approach a human for interactions, e.g., behaviors to approach by showing its intention, changing the distance between the robot and human, approaching direction to the human and behavioral switching according to the distance and time. How can the robot understand where/when/how to change its behavior and approaching strategies in human-robot interactions? To help answer this we can centralize the robot's interpersonal spaces, which can be utilized to determine when it is going to change its behaviors and approaching strategies (interaction) toward executing and achieving its goals [17][15].

Hall's [5] research about the animal kingdom has provided insight in the human experience of space by defining four personal spheres: (1) intimate distance ($0.0m - 0.45m$) for embracing, touching, and whispering, (2) personal distance ($0.45m - 1.2m$) for friends, (3) social distance ($1.2m - 3.6m$) for acquaintances and strangers, and (4) public distance ($> 3.6m$) for public speech making. A similar concept can be centralized (personal space) for a social robot to execute their social norms in human-robot interactions [4]. Hall [5] also provides a comprehensible functional and sensory explanation of the physiological-inspired factors of how human use the above spaces (proxemics). There are eight factors in nonverbal communication that are dependent upon the above spaces: posture-gender identification, sociopetal-sociofugal axis, kinesthetic factors, touching code, visual code, thermal code, olfactory code, and voice code.

Researchers in the human-robot interaction have recently been interested designing the robot's behaviors which play the key-roles in changing the physical distance between a robot and a human [11][18][20]. However, these studies explore and solidify the concept to fully understand the extent of the various factors of human proxemics and also what new factors may play a role in human-robot interactions. Predominately, we need to explore what kinds of behaviors are most desirable to use to convey the intention in each space and how human shift their interactive distances to establish positive and negative interactions with a robot.

As such, our main work aims to centralize the robot's personal space for a social trash box (STB) robot to explore desirable or optimum behaviors to establish trust in social interaction with humans and also how those behaviors are able to convey its intention or goal in each space. STB is a unique sociable robotic platform that can be defined as a human-dependent robot that cannot collect the trash by itself but needs to acquire human assistance to collect the trash. It is necessary for an STB to convey its intended behaviors to obtain assistance from a human (behavior of asking help) and on some occasions the STB has to convey its negative intention (not asking for help), which indicates it is not ready to collect the trash. Our investigation was directed to explore the following questions: (1) what are the suitable behaviors that could convey STB intentions from "asking help" and "not-asking help," and (2) what are the most optimum STB behaviors in each space to convey its intention in dynamic interactions.

2 The Concept of the Social Trash Box (STB) Robot

The concept of the human-dependent robot is relay on effective collaborate between human and robot to fulfill their mutual terminus. Since, we develop sociable trash box (STB) robot as human-dependent robot

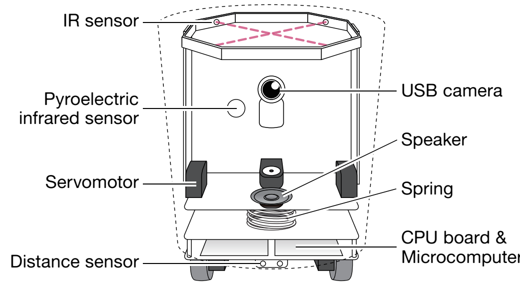

Figure 2: Designing mechanism for STB.

that synchronize human assistance with its coactions to achieve their goal. Within a crowded space, the STBs move toward the trash by engagement while using an attractive twisting motion (behaviors) and vocal interaction to convey their intentions to humans (Figure 1). The robot is incapable of collecting trash by itself, with the human having to infer the intentional stance of the robot or anticipated interaction with the STB. The ability to collect trash while also creating social rapport with a human is a novel concept. The robot engages through the use of twisting and bowing motions as the human places the trash into an STB container [19].

The STB has two parts on its body (upper and lower), with the upper part containing three servomotors - one for twisting itself to the left or right, and the other two motors for bending forwards or backwards (Figure 2). The lower part contains two servomotors for moving its entire body to the left or to the right, as well as three kinds of sensors and a single camera to obtain environmental informatics: a pyroelectric infrared sensor, an infrared ray sensor (IR sensor), and a distance sensor.

The pyroelectric infrared sensor is capable of tracing human body temperatures which are then used to discover the crowded space, while the IR sensor traces whether the trash has arrived to the appropriate container. The STB utilizes a distance sensor to avoid obstacles and to create distance between other STBs. A single webcam is used for both trash detection and recognition of other STBs through image processing. The robot preserves the following procedures to discover trash in the environment: The STB initially uses distance sensors to discover objects in the space. If an object is discovered, the optical flow is then utilized to recognize whether it is a moving object or not; if it is a moving object, the robot then decides if it is another STB or a human; otherwise, it determines that the object is trash. To move the object, image processing is employed to recognize other STBs (through color detection); otherwise, the temperature is estimated using a pyroelectric infrared sensor to discover the presence of a human in the space [19].

The advantage of the concept of a human-dependent robot is that it is not necessary for the STB to distinguish between trash and non-trash, because the concept is grounded upon the idea that both parties must collaborate with each other in order to fulfill their

Table 1: Eighteen videos were constructed for the behaviors of "asking help (represented as A)" and "not asking help (represented as N)."

Code	Ask Help Behavior	Code	Not Ask Help Behavior
$A1$	The robot pokes the trash	$N1$	Peek from behind the wall and then return to be hidden from view
$A2$	The robot pushes the trash towards the human	$N2$	Hide under the table
$A3$	The robot first bows towards the human, then bows towards the trash, and then bows towards the human again	$N3$	Do absolutely nothing
$A4$	The robot looks in the human's direction, then looks at the trash, and then looks in the human's direction again	N4	Pass by the trash
$A5$	The robot moves in a circle around the trash	$N5$	Move in a circle at a random point in space
$A6$	The robot moves towards the trash, then stops and makes a sound	$N6$	Move to a random point in space
$A7$	The robot moves towards the human, then makes a sound	$N7$	Push trash away from the human
$A8$	The robot moves towards the trash, then looks at it	$N8$	Move away from the human
$A9$	The robot moves towards the human, then looks up	$N9$	Move away from the trash

goals. Moreover, the STBs were unable to pick up the trash, and the human also desired to clean their environment (due to encouragement from the STBs). Therefore, it is necessary to have minimal technical strategies that help to convey the robot's intention and collaborate with the human in order to establish close collaboration.

3 To Convey the Robot's Intention

The STB platform is based on a unique concept which should be capable of eliciting human assistance to accomplish its goal. Behaviors of the STB should be designed and executed in two different phases in dynamic interaction: First, the STB has to carry out behaviors that convey its intention and in some stage execute the collaborate behaviors to collect the trash from the human. Second, the STB carries out its behavior by centralizing its personal space. The challenge is that we must design the behavior of "asking help" and "not asking help" for the STB, as well as explore what are the optimum behaviors in each space to convey its intention and influence to the human to establish the interaction with the STB. "Not asking behaviors" also are designed such that sometimes the robot needs to carry out negative behaviors (moving away from the human or interaction) in each space. It is interesting to explore how humans shift their spaces (personal space) according to negative behaviors ("not asking help"). In precise terms, our study aims to explore what are the most effective behaviors for "asking help" and "not asking help" for an STB to convey its intention, as well as what are the optimum behaviors in each space for the STB to convey its intention in dynamic interactions.

4 Experimental Protocol

In this study we conducted the two types of experiments: (1) to design a variety of behaviors for "help asking" behaviors and "not help asking" behaviors and to explore the most effective behaviors to convey intentions from the subjective ratings; and (2) to explore what are the most effective behaviors in each space to convey intentions in the dynamic interaction. In this experiment the participants interacted with the STB in real time.

4.1 Experiment 1: Subjective rating for goal inferences behaviors

We constructed 9 kinds of behavior where the robot seemed to be asking for help, and 9 kinds of behaviors where the robot was clearly not asking for help (Table 1). The experiment was conducted using a web-based rating system. One of the videos was randomly presented at once and participants could play the video and then rate the behaviors using a 7 point scale (from 1- "did not ask help at all" to 7- "asked a lot of help"). Each of the participants was required to rate the given videos.

Participants were assigned randomly to one of two conditions: For half of the participants, the robot displayed 'help asking' behaviors, and for the other half, 'non-help asking behaviors.' Fifty-one participants participated in the study (all students at Toyohashi University of Technology, 83.7% male, age M = 22.39 years, SD = 2.187). None of the participants had interacted with a robot before, and only 10.2% had never heard of this type of robot before. In this experiment, the six most convincing behaviors were selected (3 for help asking and 3 for the opposite).

Figure 3: Figure showed the participant interact with "ask help (left)" and "not ask help (right)"

4.2 Experiment 2: Desirable behaviors in each space

In the second experiment, we used 6 types of behavior (3 for asking help and 3 for the opposite) which were selected in experiment 1 to explore the desirable behaviors in each space in the dynamic interactions. The experiment procedure was conducted as follows: the room contained an overfilled trashcan, as well as the STB. In the beginning of the experiment, the robot started to move and performed the sequence of the "asking help" behavior or the "not asking" behavior until the participants inferred the STB's intention (Figure 3). In this experiment, the room had a motion capture system to track the participants' and STB's positions. Each participant wore three markers for tracking (head, neck, and chest), and the STB had three tracking markers on the upper-side and lower-side of the robot's container. The distance between the robot and participant, the STB behaviors, and the shifting distance of the participants with relent STB behaviors were recorded in dynamic interactions. Eleven participants participated in the experiment (between the ages of 21 and 25 years old) and all were university students from different fields of study.

5 Results and Discussion

5.1 Experiment 1: Results of the subjective ratings for goal inference behaviors

The results of subjective rating of eighteen videos are depicted in Figure 4 and Table 2. According to Figure Figure 4 and Table 2, $A1$, $A2$, $A3$, $A6$, and $A8$ behaviors received the higher rating mean values for 'asking help' behaviors, among these the highest mean rating belonged to the $A1$, $A2$, and $A6$ behaviors, which were the most effective behaviors to convey the STB intentions (Figure 4(left)). It was necessary for us to select the minimum value of subjective rating (because of the 7-scale rating system (1- "did not ask help at all" to 7- "asked a lot of help") in order to determine the most effective behaviors for the "not asking help," the results of which are $N4$, $N6$, and $N8$ (Figure 4(right)).

An independent samples t-test suggested that participants in the "help-asking" condition placed more trash into the robot (M = 1.83, SD = 1.24) than participants in the "non help asking" condition (M = 0.80, SD = 1.47); $t(47) = 2.65$, $p = 0.01$. This "trash-count" ranged from 0 to 4 pieces of trash. This difference was also found by assessing the dichotomous variable of putting trash in (yes = 1, no = 0), with an even stronger difference; 2 (1, N = 11.28, $p = 0.001$). These results indicate that people are more inclined to help the robot when it showed the "help asking" behavior than when it did not.

The selection of the most effective behaviors of the STB for "asking help" were designed based on the trash (e.g., the robot pokes the trash). Additionally, the most subjective ratings selected from the behaviors for "not asking help" were designed without concern for the trash (e.g., the robot moves away from the human). The results indicated that when conveying the STB intention, the robot's behaviors alone were not enough to elicit assistance, and that the behaviors of the STB design might provide a clue by providing attributes of the intention or goal. For example, the behaviors of "asking help" were designed based on the trash (synchronizing of the robot's behavior), and the trash became an attribute of the goal. It was necessary in the design of "not asking help" to always design the behaviors without consideration of the attributes of the goal or intention. These results were verified using an independent t-test as described in the previous section; however, the results indicated that the robot collected more trash when the STB executed the "asking help" behaviors more than the "not asking help" behaviors. Furthermore, when we designed the STB behaviors to elicit assistance ("asking help"), it was necessary to design the behaviors by considering the goal attribution (trash), and the "not asking help" was not considered as a goal attribution in designing STB behaviors.

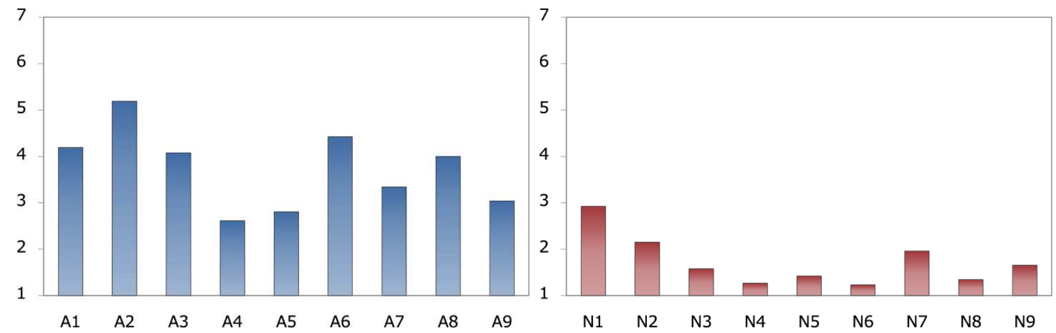

Figure 4: The figure shows the mean values of the subjective ratings for eighteen behaviors of "asking help ($A1$ to $A9$)", and the mean values of opposite ("not asking help ($N1$ to $N9$)") behaviors. The x-axis represents the behaviors and y-axis represents the mean values of the subjective ratings.

Table 2: Mean/Std.deviation values of subjective ratings for "asking help ($A1$ to $A9$)" and "not asking help ($N1$ to $N9$)."

Code	Mean / Std. Deviation	Code	Mean / Std. Deviation
$A1$	4.19, 1.650	$N1$	2.92, 2.296
$A2$	5.19, 1.919	$N2$	2.15, 1.713
$A3$	4.08, 2.038	$N3$	1.58, 1.474
$A4$	2.62, 1.627	$N4$	1.27, 0.724
$A5$	2.81, 1.674	$N5$	1.42, 0.857
$A6$	4.42, 1.815	$N6$	1.23, 0.652
$A7$	3.35, 1.788	$N7$	1.96, 1.536
$A8$	4.00, 1.414	$N8$	1.35, 0.977
$A9$	3.04, 1.886	$N9$	1.65, 1.384

Table 3: Mean difference between participants's approaching distance (acceleration) and STB's behaviors

Behaviors	Participants	Results (t-test)
Asking	Subject1	*P = 7.62E-09 < 0.05
	Subject2	P = 0.576 > 0.05
	Subject3	P = 0.386 > 0.05
	Subject4	*P = 4.48E-09 < 0.05
	Subject5	P = 0.307 > 0.05
Not Asking	Subject6	P = 0.250298 > 0.05
	Subject7	*P = 7.42E-10 < 0.05
	Subject8	*P = 4.73E-06 < 0.05
	Subject9	P = 0.176 > 0.05
	Subject10	*P = 3.03E-25 < 0.05
	Subject11	P = 0.726 > 0.05

5.2 Experiment 2: Result for desirable behaviors in each space

As we described in the experimental protocol, we selected the higher ratings for "asking help ($A1$, $A2$, and $A6$)" behaviors and "not asking" behaviors ($N4$, $N6$, and $N8$). In this experiment, half of the participants were assigned to interact with the "asking help" behaviors and the other half were assigned to interact with the "not asking" behaviors. The STB continually executed three kinds of behaviors (either "asking help" or the opposite) with some sequences of idle periods in between the two consecutive behaviors.

In this section, we are mostly interesting in exploring the manner of the participant's approach (change of distance between the robot and participants) to the STB based on its behaviors. Through the motion capture system we gathered the participant's moving distance and STB location according to time. A participant's moving distance with time-interval was utilized to estimate their moving behaviors or reaction-behaviors (acceleration) relevant to the STB's behaviors. The estimation was performed as follows: we calculate the participant's moving distance (current position to another position) with the time spent for the relevant movement, which provided information of how quickly the participant responded to the relevant STB behaviors. A similar approach was applied to estimate the participant's reaction (acceleration) when the STB was in an idle state. The sensitive parameters of acceleration were used to estimate the participant's reaction behaviors, rather than just considering the shifting distance of the participant. Here, we considered the entire interaction of each participant's reaction-behaviors (acceleration) in each time interval for the "asking" behaviors and "not asking" behaviors. As shown in Table 3, we applied an independent t-test to evaluate the mean difference of the participant's acceleration (moving vs. idle) when the STB executed behaviors vs. the idle state.

Table 3 shows the mean difference of acceleration for each of the participants when the STB performed the "ask help" and "not ask help" behaviors. The parameter of acceleration is represented when the STB performs the behaviors and then how the participants responded. The overall results show that some of the participants started to respond when the STB executed the behaviors than during the idle state. These results highly suggest that the STB behaviors played roles in conveying the STB intention, motivating the response, and influencing a shift in the interactive space in the robot's personal space (distance between the robot and participants).

The second part of the analysis was directed toward exploring what types of behaviors were most important in each space to convey the robot's intention. We considered the participant's moving distance with time by synchronizing the sequence of STB behaviors. The following Figure 5 shows the participant's moving distance with relevant time in each space for "asking help ($A1$, $A2$, and $A6$). The results indicate that $A1$ (robot pokes the trash), and $A6$ (robot moves towards the trash, then stops and makes a sound) were the most effective in personal space, while $A2$ (robot push the trash toward the human) behavior was the most desirable behavior in social space. The intimate

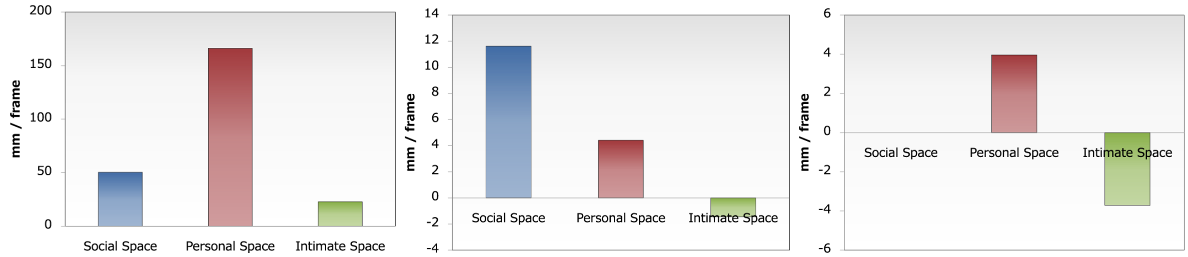

Figure 5: The figure depicts the mean value of the participantfs moving velocity in each space for the robot's "ask help" behaviors; $A1$(left), $A2$(center), $A6$(right)

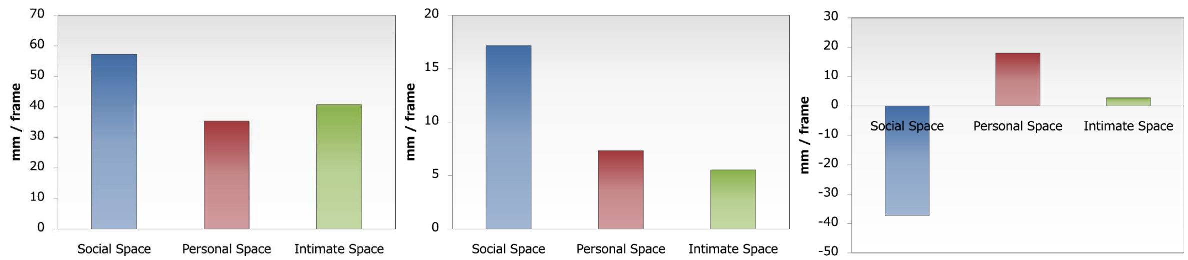

Figure 6: The figure shows the participant's moving velocity in the relevant STBs behaviors "ask help" behaviors; $N4$(left), $N6$(center), and $N8$(right) in each space.

space had a very short distance (45cm) between the robot and participant, and we believe the participants had already recognized the STB's intention and had collected the trash to the robot if somebody was in the intimate space. Therefore, it was not necessary for the STB to execute any explicit behaviors except greeting behaviors (after collect the trash) in the intimate space. The results revealed that if the STB and participant had a distance which was approximate to the social space, the most suitable behavior of STB was $A2$ (the robot pushes the trash toward the human) to convey its intention. This result signified that when the robot has a considerable distance with a participant then the STB has to push the trash toward the human to convey its intention to the participant. When the STB and participants had a close distance as a personal space, the behaviors of $A1$ (robot pokes the trash), and $A6$ (robot moves towards the trash, then stops and makes a sound) are the most desirable to convey its intention. We can conclude from the overall results that when the STB and participant had a considerable distance between them, then the STB had to execute its behaviors toward the direction of the participant based on its goal-based implicit activities, although it had to execute more explicit behaviors (robot moves towards the trash, then stops and makes a sound) when the distance between the STB and participant was short.

We followed the same procedure as above for the "not asking help" behaviors to explore the most effective behaviors in each space (Figure 6). The results did not provide clear guidelines for the robot to perform the most desirable behaviors in each space, except for the $N8$ (move away from the human) which was most effective when the STB and participant had a considerable distance as a boundary of social space. From the result, we believe that the STB should execute the behaviors for "not asking help" without considering the goal attribution (trash), which should be considered when designing and executing dynamic interactions.

6 Conclusion and Future Work

The results of the study suggest that goal attribution (trash) based-activities (e.g., the robot pokes the trash) should be considered to design the "asking help" behaviors, while the "not asking help" behavior should not be considered in the goal attribution activities to design STB behaviors. When the STB and participants have a considerable distance, the STB then has to execute its behaviors toward the direction of the participant based on its goal-based implicit activities (e.g., the robot pushes the trash toward the human). However, the STB had to execute more explicit behaviors (e.g., robot moves towards the trash, then stops and makes a sound) within the short distance between the STB and the participant. Additionally, the STB executed the behaviors for "not asking help" without considering the goal attribution (trash) by ignoring the human assistance in dynamic interactions. As a future work, we expect to integrate these interactive roles by centralizing the STB's personal space with Simultaneous Localization and Mapping (SLAM), which may help to facilitate STBs in performing autonomous and social behaviors in a dynamic environment.

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