Spot Making Social Body Language

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***Abstract*—One approach to facilitating human-robot interaction is to enable robots to communicate in a way that is already familiar to humans. Realistic canine-like behavior is one such pattern of body language that is recognizable. This paper explores how adding popular canine social behaviors to a quadruped robot can allow humans to perceive it as more canine-like. For this experiment, participants are surveyed on what behaviors they found "canine-like". The results are compiled and developed into a library of social behaviors that we programmed into Boston Dynamics's robotic quadruped, Spot. Finally, a randomized inter-participant survey is conducted, in which some participants are shown a demonstration of the robot with the social canine behaviors, and others are shown a demonstration of the robot without. Both groups are asked to rate how canine-like they perceived the robot. Survey data supports the hypothesis that the robot is perceived as more dog-like with the social canine behaviors, as opposed to without.**

I. Introduction

Most social interactions depend on both participants communicating using a mutually understood language. The desire for the establishment of a common channel of communication between robots and humans has motivated research into robots responding to verbal (speech recognition, voice activation, etc.) [1] and nonverbal (gaze, body language, etc.) [2] [3] cues; however, there are not many established methods by which robots can communicate with humans in a manner that requires little user adjustment or explanation. One method of establishing a mutually understood channel of communication is by having robots imitate behavior already known to people. For example, humans have been familiar with canine body language for a long time and are able to understand their communication patterns based on past experience.

This experiment modifies the behaviors of Boston Dynamics's robot quadruped, Spot, by adding canine-like social body language to its library of movements. Spot is a robot consisting of a torso and four legs with the agility and flexibility to mimic real-world canine behavior. We first conduct a survey among voluntary participants to determine what body movements they associate with canine-like social body language. Based on the most popular responses, we program Spot to recreate tail wagging, looking at people, walking in circles, sitting, and play bow. Finally, through a randomized inter-participant design, we demonstrate both patterns of behaviors to different groups, with one group viewing a demonstration of the robot without canine social behaviors, and one group viewing a demonstration of the robot with the added canine social behaviors. We record participants' self-reported perceptions through a questionnaire. While human-robot communication has been studied before, our study focuses on the ability of a robot to communicate in a way that is familiar to humans without adjustment or explanation.

II. Background

Spot by Boston Dynamics is a quadruped agile mobile robot that has the physical appearance of a dog. Spot's features include mobile manipulation, a 3D vision system with SLAM and obstacle avoidance, and the ability to ascend and descend stairs. While Spot may seem like a dog physically, the behavioral functions of the robot do not match that of a dog [4]. Dogs are known to interact with each other and people through body postures, facial expressions, tail and ear positions, raising of hair or "hackles," vocalizations, and scents [5]. These are also known as canine social behaviors that humans associate with dogs.

Canine social behaviors are established based on canine body movements. Canine movements are derived from the quality of the movement, such as walking versus running, or based on the different positions required for that movement like vertical versus lateral movements [6]. Likewise, behaviors can be examined separately – a "yawn" or a "paw raise," – or pooled together to describe behavioral states that humans would identify as friendly or aggressive. Behaviors can also be described by their frequency, duration, and intensity which then loops them into different behavioral pools [7] [8].

Canine movements are most often discerned through a dog's tail. Tails can be perceived in many ways, but the details of a tail's movements are presented through the base of the tail. From the base, it can be seen if a tail is high, midline, or low, thus indicating a dog's behavior. A high tail, for example, can indicate excitement and can be seen in a variety of approach-oriented behaviors, ranging from greeting and playing to fighting and threatening [9]. In addition, the movement of the tail is one of the most noticeable things about a dog. A tail wagging from side to side at the midline is most readily associated with greeting or excitement [7]. The canine social behavior of wagging a tail is an effective way to communicate between dogs and humans as humans perceive a dog that wags its tail as "happy" [10]. Tails are just one example of a movement that constitutes behaviors. Other examples include movement of the ears, eyes, mouth, and body weight distribution which all affect how dog behavior is shown and perceived.

Body Movement	Roll (rad)	Pitch (rad)	Yaw (rad)	$velocity_x$(m/s)	Rotation Angle (rad)	Number of Trajectory Points
Tail Wagging	-π/16 to π/16	0	-π/8 to π/8	0	0	3
Play Bow	0	0 to 3π/14	0	0	0	1
Sit	0	-π/7 to 0	0	0	0	1
Walk in Circle	0	0	0	2	-1.5 to 1.5	12
Spin	0	0	0	0	-1 to 1	8

TABLE I: Body Movement Values and Trajectory

Canine social behaviors affect the temporal behavioral pattern, changing how humans interact with a robot dog. In order to achieve interactions like that of a human with a living dog, robot dogs need to implement behaviors such that humans do not feel "bored" or "tired" of the interactions [11]. This way of communication, if implemented on a robot dog, can not only make the robot act more like a dog, but give it a recognizable emotion that humans fundamentally understand [12].

III. Related Works

The field of human-robot dog interaction has been explored mainly through the use of the AIBO robot dog from Sony. Humans are seen to interact with robot dogs differently than they interact with live dogs due to the limited ability of the robot to engage in temporally structured behavioral interactions with humans [13] [14]. During playtime between humans and AIBO, their interactions were similar to those between the human and the living dog [13]. However, the differences in the behavior between the living dog and AIBO were still prominent as the living dog moved around and laid down more than AIBO did. Thus, the actual canine behaviors of AIBO were more limited than how humans interacted with it [15].

Furthermore, one study evaluated the consumer's perceived relationship with AIBO and found that most have a close bond with the robotic animal and continue to play with it in their daily lives. They also formed a bond with the robot indicated by the assertion that "42% have feelings for AIBO" [16] [17]. And since AIBO can evolve from a "puppy" to a "dog", it made the robot seem more like a living animal which led to higher social engagement from the consumer. Users characterize their relation to AIBO to some degree in an analogous way as to a living dog, assign animal traits to it, treat it as a social "friend," and regard it as part of the family [18]. Hence, users do forge some form of human-animal attachment to AIBO even though it is a robot [14].

IV. Methodology

A. Phase 1: Human Surveying for Social Perception

In order to determine what could be reliably constituted as "social body language" from a human perspective, we surveyed 57 individuals. The survey was distributed primarily through social media to college-aged individuals. The individuals were voluntary participants and responded to a series of questions asking how they thought dogs behaved when feeling different emotions: friendly, happy, aggressive, anxious, sad, and relaxed. Finally, the participants were shown a brief clip demonstrating normal use of the Spot robot and were asked how Spot could change its behaviors to seem more canine-like. The results of this survey were analyzed, graphed, and used to determine what movements we would add to Spot to enable it to behave socially and interact with humans organically (See Section 5A: What Constitutes Social Body Language?).

B. Phase 2: Developing Organic Social Body Language

Spot exists on a 3D plane, in which we control the roll, pitch, and yaw of the torso to produce body movements. Changing roll tilts the torso from side to side, changing yaw tilts the torso towards one diagonal or another, and changing pitch tilts the torso forward or backward. The frame that we are rotating is the center of the body mass. Additionally, $velocity_x$ and $velocity_y$ are used to plan the trajectory and change the position of Spot. For our purposes, we do not directly alter the $velocity_y$.

For each body movement, we create a trajectory, which includes points that the torso had to reach the position of in a certain amount of time for each movement. When we plan each trajectory, we need a time frame for each point in the trajectory. We determine that the most organic-seeming time frame between trajectory points (fast enough to seem life-like and slow enough that the motor movements do not appear abrupt) is 500 milliseconds. This means that each trajectory point occurs in increments of 500 ms. Each trajectory point is packed into a method that plans out the trajectory and executes it.

The ranges for roll, pitch, yaw, $velocity_x$, the angle of rotation, and the number of trajectory points for each body movement are visible in Table 1.

One of the survey results involved smoother motions, and part of our original goal was to make Spot's motions more organic. In order to make movements more fluid, we included midpoints between trajectory points of body movements to avoid jerky motions from the motors. Additionally, we combined some body movements to achieve more realistic and life-like motions such as play bowing or sitting while tail wagging. This is because it is unlikely that actual canines will only exhibit one movement at a time.

1) Tail Wagging: In the "tail wagging" motion, the yaw and roll are changing since the hind should be moving from side to side at their diagonals. A mapping was created from one extreme of yaw and roll to the other extreme. Yaw and roll are of opposite negation.

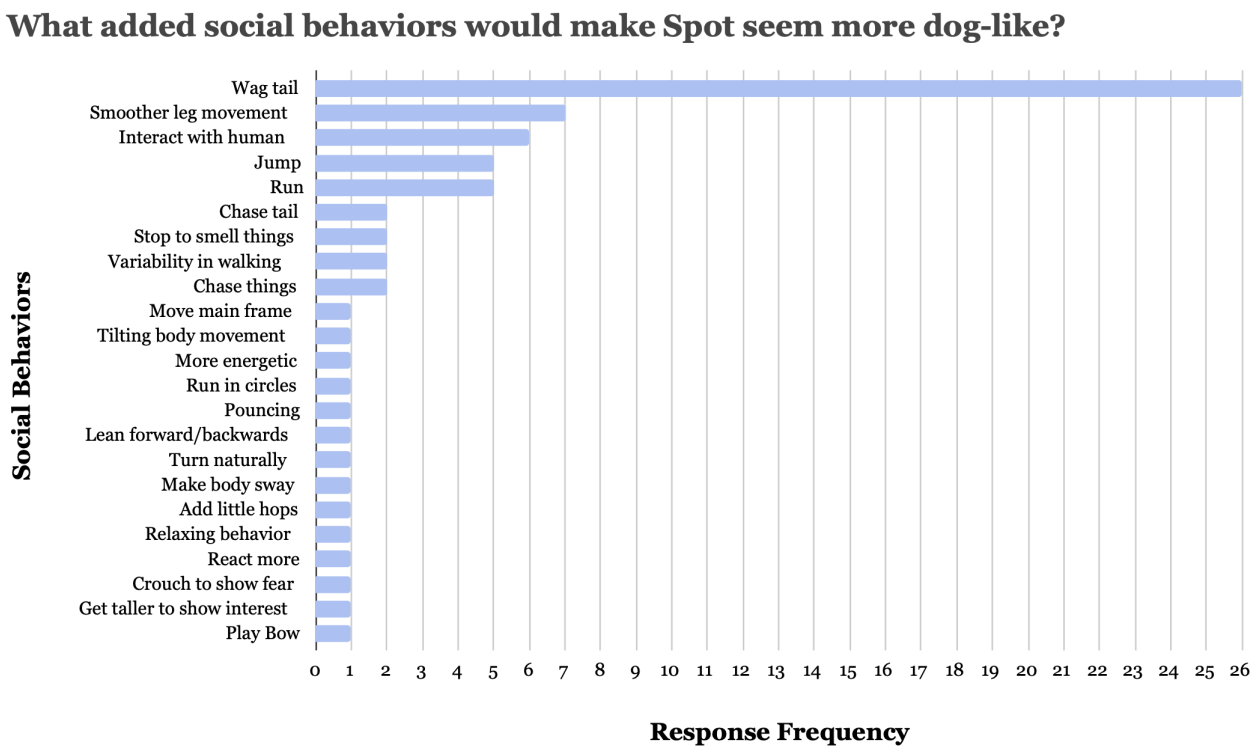


Fig. 1: Results of the human survey on perception of dog-like social behaviors, in order to determine how to make Spot seem more canine-like.

Since smoothness of tail wagging was essential, we anchored the midpoint at the center. Thus, Spot tilts to the right, returns to the center, tilts to the left, returns to the center, and continues.

2) Play Bow: In the "play bow" motion, the pitch is changing, and the torso of Spot rotates all the way forward, while the yaw and roll remain unchanged.

3) Sit: The "sit" motion involves the opposite movement of play bow, to a less extreme extent. The pitch is rotated backward to tilt the torso back so that Spot can look up at humans and interact with them.

4) Walk in Circle: To make Spot to walk in a consistent circle, the velocity for each trajectory point is the same. The rotation of 1.5 signifies that each time Spot walks, Spot is changing relative to its current position, rotating 1.5 radians (counter-clockwise) or -1.5 (clockwise).

5) Spin: The "spin" motion was developed to mimic a dog chasing its own tail, which was one of the popular survey responses. Although Spot does not possess a spine and cannot twist to mimic actual tail-chasing, spinning is the closest behavior Spot can make. In this motion, the rotation changes without changing roll, pitch, yaw, or velocity, since the torso angle is not changing, and neither is the actual position. When Spot executes the "spin" movement, it has a rotation angle of 1 (counter-clockwise) or -1 (clockwise).

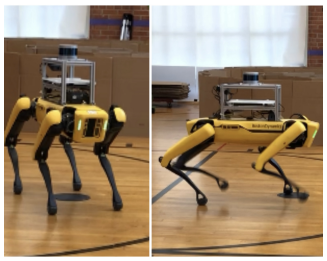
C. Phase 3: Human Surveying for Understanding Spot's Social Body Language

In order to test the implemented body motions, we conducted an inter-participant survey with two demonstrations to analyze the degree to which how much Spot resembles a canine with versus without canine social behaviors. The survey was conducted on the intersection of 24th Street and Speedway on UT Austin's campus in order to get a high traffic of randomized people. In total, 113 people participated in the survey with the participants from varying demographics. Our participant pool consisted of UT Austin students, UT Austin faculty and staff, as well as individuals touring the campus. In our survey, we asked one question: "How canine-like does Spot seem?" and asked each participant to watch a demonstration and then to rate the canine resemblance of Spot on a scale of 1 to 10.

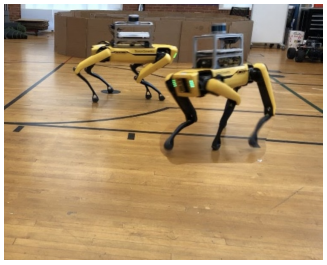
We created two demonstrations to show to participants. The first showcased Spot without the created canine behaviors and had it walk forward, backward, and side to side. The second demonstration showed the implemented canine social behaviors: tail wagging, play bow, sitting, walking in a circle, and spinning. Each participant was exposed to only one demonstration and each demonstration was conducted on a different day. Participants also did not know what demonstration they were being shown or that there were two different

(a) Play bow

(b) Sit



(c) Spin



(d) Walk in circle

(e) Tail wagging to the left and right

Fig. 2: The library of Spot's social body movements

demonstrations.

V. Results

A. Phase 1: What Constitutes Social Body Language?

After we obtained the results of the first survey regarding the perception of dog-like social behaviors, we determined the commonalities and popularity of the responses in order to determine which social behaviors were most naturally associated with canines (see Figure 1). From this survey, we selected the most popular responses: wagging of tail, smoother leg movement, interacting with a human, and chasing its tail. Responses that involved jumping were discarded as Spot is not able to jump in a way that seems realistically canine-like. As were responses that involved running, since Spot cannot move at a speed fast enough to imitate a live canine running. We also discarded responses that involved altering body parts rather than body languages, such as facial, ears, and eye movements. From these filtered responses, we combined them into cohesive canine-like gestures to add to Spot's library of body movements. We added tail wagging, interacting with a human, play bow, walking in circles, and chasing its tail. Additionally, we added a variation of leg movements to make it seem more organic and trajectory midpoints to make the transition from one position to another much smoother. These canine-like gestures are what comprise our library of Spot's social body language.

B. Phase 2: Spot's Social Body Language Library

Using the approach described, we developed the following body movements for Spot: tail wagging, interacting with a human, playing bow, walking in circles, and chasing its tail, as shown in Figure 2.

We developed a demonstration of these canine social behaviors, which enabled Spot to interact with a human participant, and a demonstration of Spot without the canine social behaviors, that demonstrated the mobility of the robot.

1) Canine behaviors demonstration: Spot walks in a circle, spins, then performs a combination of wag tail and sit, then performs a combination of wag tail and play bow

2) Non-canine behaviors demonstration: Spot walks forward, backward, leftward, rightward. Spot turns 90 degrees, and then repeats these movements.

C. Phase 3: Human Survey

We use the human survey detailed in subsection IV-C to measure information on the change of the degree of resemblance to a live canine with and without added social body language to the Spot robot. The survey remained anonymous in order to encourage honest responses. In order to show the significance of our results, we include the results of one-way analysis of variance, or ANOVA ($p = 0.019$, r = 0.7), displayed in Figure 4.

The average canine resemblance for Spot without added canine social behaviors was a 6.77, and the average canine resemblance for Spot with added canine social behaviors was a 7.69 (see Figure 3). 78 participants watched the Spot demonstration without canine social body movements and 35 participants watched the Spot demonstration with canine social body movements, resulting in a significant difference across the two conditions ($p < 0.05$).

See Figure 5 for a graph of the responses of participants who completed the survey, across the two conditions. The graph demonstrates a visible difference in means. Figure 6 shows the difference in the median of both distributions. Furthermore, it demonstrates the difference in the standard deviations: 2.051 for non-canine behavior and 1.451 for canine behavior. The widely dispersed responses for the non-canine behavior demonstration suggests uncertainty and a lack of a consensus, while the more concentrated canine-behavior distribution suggests the opposite.

VI. Discussion

Something that may have impacted the results of our study is the novelty of Spot. It is possible that due to the modernity of the Spot quadruped robot, people are conditioned to see the canine-resemblance in any quadruped robot that has the mobile potential of a dog, even without canine-like behaviors. It is possible that when the robot is more well-known,

Report

How canine-like does Spot seem?

Behavior type	Mean	N	Std. Deviation
Non-canine behavior	6.77	78	2.051
Canine Behavior	7.69	35	1.451
Total	7.05	113	1.927

Fig. 3: Report on Means

Tests of Between-Subjects Effects

Dependent Variable: How canine-like does Spot seem?

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	20.292[a]	1	20.292	5.697	.019
Intercept	5047.974	1	5047.974	1417.149	<.001
condition	20.292	1	20.292	5.697	.019
Error	395.389	111	3.562		
Total	6037.000	113			
Corrected Total	415.681	112			

a. R Squared = .049 (Adjusted R Squared = .040)

Fig. 4: Univariate Analysis of Means. $n_{non-canine}$ = 78, n_{canine} = 35, α <0.05. The question was answered on a scale of 1 to 10.

the means in the canine-resemblance of both demonstrations will differ more widely. It is also possible that in the non-canine behaviors demonstration, participants are falling prey to pareidolia, the human tendency for perception to impose a meaningful interpretation on nebulous or otherwise confusing stimulus [19], since many participants expressed how canine-like the robot seemed even before the demonstration. This implies that people recognize a quadruped robot as a robotic dog solely based on its physical appearance, despite the lack of resemblance to a live canine (no face, ears, or tail, not a color that occurs naturally in canines), and the only seeming similarities are the torso, four-legs, and the size.

Another interesting topic for further inspection would be whether physical or behavioral aspects have a greater effect on the seeming degree of canine-like resemblance. In the pre-survey, many of the responses involved changing aspects of Spot that were not behavioral, such as adding eye movements, a face, and a tail. The acceptance and recognition of Spot as a canine enables humans to better understand the canine social body language. If humans cannot perceive the robot as a true canine, it could impede them from recognizing which mutually-understood language channel the communication is being sent through. It is a possibility that at some point, the efficacy of adding new canine behaviors would plateau in terms of increasing Spot's resemblance to a canine, and adding physical canine-like features would increase the degree of canine resemblance and better enable humans to understand Spot's social communication.

VII. Conclusion

Our goal is for Spot to achieve fluid, organic social body gestures that emulate real canine behaviors to improve people's perception of Spot. People are still hesitant to either interact with or share a space with a robot, especially with what can appear to be an alien robot failing to imitate a dog. With Spot performing live canine behaviors, humans can view the behaviors as more natural and organic to their environment (through tail wagging, looking at people, walking in a circle, sitting, and play-bowing). We conducted our experiment to demonstrate Spot's new social behaviors to make it appear more canine-like. Based on our results, we conclude that there is a significant difference in the canine resemblance of Spot with added canine social behaviors and without canine social behaviors. Humans perceive a quadruped robot with behaviors they are familiar with – more specifically, behaviors that allow the Spot to interact with a human participant – to be more organically canine-like than a robot without these interactive behaviors.

We can continue to program more canine social features on Spot and test whether this further increases Spot's canine resemblance. Since this study determines that added canine social body movements results in an altered human perception regarding the degree of canine resemblance, in order to prove that familiarity of body language is an efficient channel through which robots can communicate with humans, future research will involve investigating the degree of success of this attempted "communication". Specifically, whether humans are able to understand and interpret Spot's body language, and whether it can be used to effectively communicate a comprehensible message. Only after humans can interpret Spot's body language and its true meaning can a true channel of communication between humans and robots be established.

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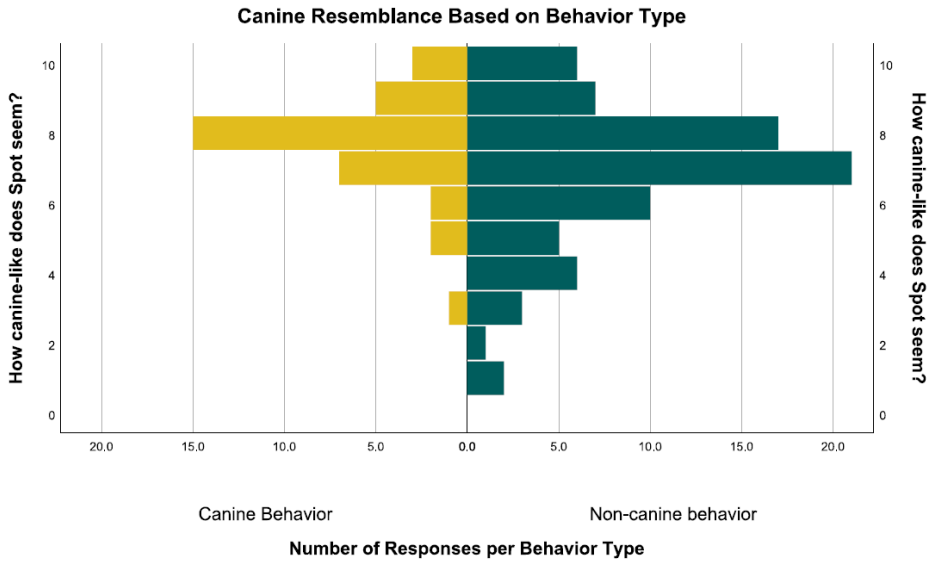

Fig. 5: Histogram of Data Collected from Human Survey

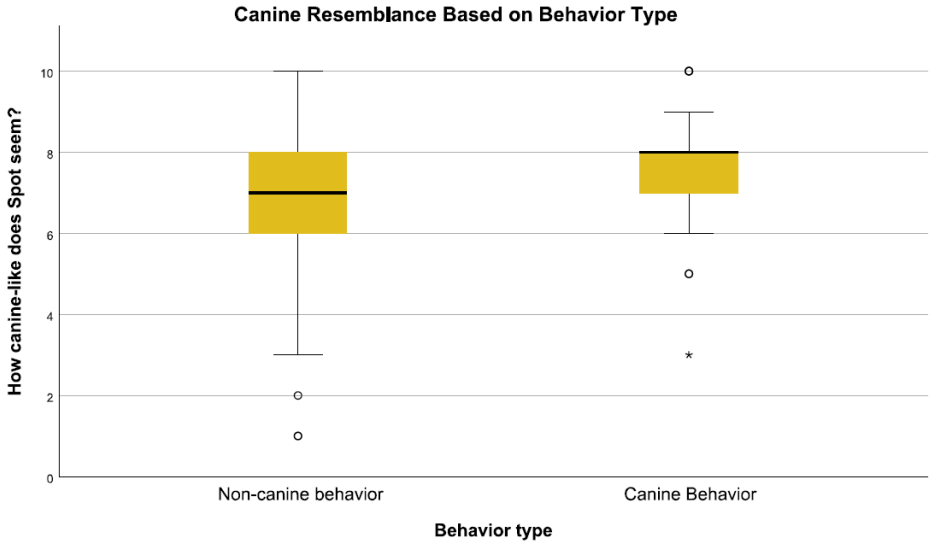

Fig. 6: Boxplot of Data Collected from Human Survey

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