Look to my Lead: How Does a Leash Affect Perceptions of a Quadruped Robot?

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***Abstract*— Emerging applications requiring robots to operate in close proximity to people have mandated an understanding of how to enable graceful robot navigation in shared spaces. Existing social navigation research mainly observes a person or group walking past a single, independent robot. Consider the relationship between a dog and a handler carrying its leash. The emergence of widely-available quadruped robots - often conceptualized as robot dogs - opens a variety of interactions by transferring the canine metaphor to the area of social navigation. This research shifts focus from people walking past a single robot in a shared space to people walking past human-robot dyads; where the robot takes on the role of a dog. In this study, participants see each of five conditions, in which the robot is presented differently. The conditions are: "Fully-Autonomous" - in which the robot traverses the hallway by itself, "Remote-Controlled" - in which the a researcher follows the robot while holding a controller, "Companion" - in which a researcher walks alongside the robot, "Leading" - in which a researcher follows the robot while grasping a service dog harness, and "Guided" - in which a researcher holds the robot on a leash. After episodes of passing the human-robot dyad in a hallway, participants respond to a questionnaire measuring their attitudes towards the robot in the interaction. The results of this work are promising. Though a questionnaire administered between study conditions asking participants to rate their perceptions of the robot yields few statistically-significant results, a questionnaire administered at the end of the study asking participants to compare the conditions to each other provides significant differences in how the participants rate the robot.**

I. Introduction

The emerging availability of quadruped robots (often called robot dogs) opens a variety of interactions in which the robot is presented not in solo but as part of a human-robot dyad. People are used to seeing dogs with *handlers*; pet owners, service dogs users, and others. This work observes the reactions of study participants after they have passed a Boston Dynamics Spot in a hallway when the robot has been placed in one of five cynomorphic roles. These roles are: a *Fully Autonomous* mode, where the robot navigates the environment without a handler; a *Remote-Controlled* mode, where the handler follows the dog while holding a controller; a *Companion* mode, where the handler walks side-by-side next to the robot without any controller or leash; a *Leading* mode, where the robot wears a service dog vest with the handler holding a guide dog harness; and a *guided* mode, where the handler holds the robot by a leash.

Interactions in this work take place in a test hallway constructed for social navigation experiments. The study is set up as a five condition intraparticipant design, in which each participant sees each condition. In every condition, the robot operates fully-autonomously; running a custom social navigation stack developed for this experiment. The robot is programmed to detect which side of the hallway the study participant is on — modeling the hallway as three "traffic lanes" — and to move to the opposite side of the hallway in order to allow the participant to pass. After each interaction, participants respond to a questionnaire including measures from Godspeed Questionnaire [1] as well as additional measures relating to potential robot deployments from our research team. This work seeks to provide novel contributions to the existing literature on factors influencing human perception and acceptance of robots; and to inform the design, development, and deployment of autonomous service robots — quadrupeds in particular — in urban spaces where they are likely to result in handler-robot-pedestrians encounters.

This study continues a trend in Social Navigation and HRI more broadly of expanding beyond dyadic interactions into more complex configurations of humans and robots [2]–[6]. As robot deployments become more common, there is a growing recognition that HRI has an ethical duty to expand its scope to include all people potentially impacted by the robot's presence [7], [8].

II. Related Work

This study is designed to inform social navigation research on the topic of robots accompanying a human handler by observing reactions to a human-quadruped robot dyad.

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Social Navigation in Robots Social Navigation is a well-established task in HRI centered upon enabling robots to perceive, react to, and conform to social norms of movement [9], [10]. Some significant work on this task has examined collision avoidance [11]–[13], comfort [14]–[16], smoothness of interaction [17]–[19], effort invested [**?**], [20] and other objective and subjective measures of social acceptability when pedestrians and a mobile robot move in a shared space. Social Navigation research often implements autonomy based upon identifications of social cues or socially-informed predictions of human movement [21], [22], and has even progressed to studies of robot ability to (socially) signal navigational intentions [13], [23]–[26]. Social Navigation as a whole is deeply informed by empirical findings about [27]–[30], models of [31]–[33], or training data containing [34]–[36] human social navigation norms. This study provides empirical findings of human perception and reaction to quadruped service robot encounters that can inform future research.

Perceptions of quadruped service robots The relative dearth of HRI studies of quadruped platforms in service applications means that public perceptions are poorly understood, even as they are entering wider use and visibility. Moreover, media portrayals of quadruped robots, which have been shown to influence perceptions of robots [37], have unknown impacts these perceptions. Media coverage likely to influence public perceptions includes general interest pieces on "robot dogs" (often with an alarmist tone; e.g., [38]), news coverage and research reports on deployments by public health and safety organizations [7], [39], and these platforms' growing use in marketing campaigns, such as the 2022 Samuel Adams Superbowl ad featuring Boston Dynamics Spot [40]. The longer this gap in research persists, the more difficult it will be to identify and characterize changes to and influences upon perceptions of service quadrupeds, and to articulate how they vary across cultures and within subcultures [41].

HRI of Quadruped Service Robots and Canine Metaphors

Quadruped platforms intuitively suggest canine interaction metaphors and usage. Indeed, one of the most developed areas of research has been the study of their use as guide dogs to assist visually impaired users with navigation [42]–[47]. Related research specifically targeting assistive use cases, but employing canine metaphors; includes cynomorphic and general zoomorphic expressions [48]–[50], leash-based interfaces [43], [51], and dog-inspired interaction design [52], [53].

Service-Robot-Pedestrian Encounters

There is a growing literature in HRI and adjacent fields — such as smart cities — regarding pedestrian-robot interaction; much of it very recent [54]–[59]. In light of this recency, many studies have adopted an exploratory approach [60]. Researchers outside HRI have also begun to examine these issues; often from critical, ethical, or justice-focused perspectives [8], [61]–[65]. This work builds upon and is motivated by work on long-term autonomy [66]–[68], which has increased the number of human-robot encounters.

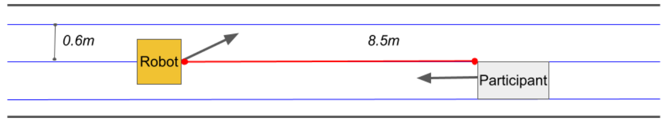


Fig. 1: Diagram of the operation of the social navigation stack. The robot operates in a hallway that is 1.25m wide. Three lines representing "lanes" are laid out in the hallway, 0.6m apart. The robot shifts lanes when it comes within 8.5m of the participant.

While the literature around encounters — as opposed to the direct interaction that is the traditional object of HRI studies — continues to expand, encounters with quadruped service robots remain poorly understood. This represents an important gap in current knowledge, which is particularly urgent to address as quadruped deployments become more common, and in light of the inherent differences in perception of robots by platform and style of locomotion.

III. A System for Autonomous Hallway Passing

For this study, the robot's behavior should be consistent across trials, ensuring that all participants have similar experiences. To accomplish this a custom social navigation stack has been developed. The social navigation stack assumes that the study participant begins at one end of a test hallway set up in our laboratory, with the robot beginning at the other end. The participant and robot, each walking to the opposing end of the hallway, will pass at some point. The system divides the hallway into three traffic lanes (similar to [25] and [**?**]). The robot navigates by following one of these lanes, always starting in the middle lane. When the robot comes within a threshold distance of the participant (8.5m; hand-tuned for this study), it shifts to the lane that is on the opposite side of the hallway of the participant, making room to pass. See Figure 1.

A. Robot Platform

For the experiment, the Boston Dynamics Spot robot is equipped with a laptop (Ryzen 9 5900HS, RTX 3060) running Ubuntu 21.10 and ROS Noetic in a Docker container, a Velodyne VLP-16 LiDAR and a Microsoft Azure Kinect point cloud camera. The robot, as equipped for the study, can be seen in Figure 2.

B. Navigation

The robot is localized using an implementation of Episodic non-Markov localization (ENML) [69] using a map of the hallway area. Navigation goals are given to the robot as ROS twist messages, translated to the Spot's protocol using the Clearpath Spot ROS Driver[1]. Visualization of the robot's state information is provided to robot operators (when initially setting up the robot) through Robofleet WebViz [70], a browser-based visualizer that connects to ENML.

[1]https://github.com/clearpathrobotics/spot_ros

Fig. 2: The Boston Dynamics Spot robot as equipped for this study; including a laptop, Velodyne VLP-16 LiDAR, and a Microsoft Azure Kinect point cloud camera.

The hallway is modeled as three traffic lanes, as illustrated in Figure 1. The hallway is 1.8m wide, and the lanes are modeled as lines, each 0.6m apart, with one lane in the middle of the hallway. The robot navigates by choosing waypoints that are 2.75m in front of it on the lane that it wishes to navigate on. Thus, if the robot is continuing on the same lane, it is 2.75m ahead on the same lane. If the robot is shifting lanes, it is 2.75m ahead on the lane that it is shifting into. This distance is hand-tuned to produce a smooth-looking lane-shifting behavior.

C. Pedestrian Detection and Control Algorithm Behavior

To detect people in the hallway, the navigation stack uses the Azure Kinect Body Tracking SDK[2]. The SDK provides the pose of the person relative to the camera as a track consisting of landmarks on the body. The chest is transformed into the global frame using the ROS TF2 service. The distance of this landmark from the left or right wall is computed in order to determine which side of the hallway the pedestrian is on. When the robot comes within 8.5m of the study participant, it shifts lanes to the lane opposite that which the participant is measured as being in.

IV. Methodology

This study was approved by the University of Texas at Austin Institutional Review Board under Study #00002514. A total of 26 participants were recruited from the University of Texas at Austin campus. One participant is excluded from data analysis for failure to complete the entire questionnaire.

A. Design

After informed consent and an optional media release are obtained, participants are directed to one end of the test hallway, with the robot placed in the middle lane at the other end. After the hallway interaction, the participants fill out a questionnaire rating their attitudes toward the robot. This interaction is repeated 5 times, exposing each participant to each condition in randomized order. For each condition, the robot is presented differently. The robot, as outfitted for each condition, can be seen in Figure 3. The conditions are:

Fully-Autonomous The robot traverses the hallway by itself with no additional costuming.

Remote-Controlled The robot traverses the hallway with a researcher following behind, holding a game controller, pretending to control the robot.

Companion The robot traverses the hallway with a researcher walking next to it.

Leading The robot traverses the hallway with a researcher walking slightly behind it, holding onto a service dog harness. The robot wears a service dog vest.

Guided The robot traverses the hallway with a researcher walking slightly behind it, holding onto a leash.

After completing the five conditions, participants complete one final survey, comparing the conditions to each other. After concluding the study, the participants are debriefed, revealing the purpose of the study as well as the deception that the robot is always operating fully-autonomously.

B. Questionnaire

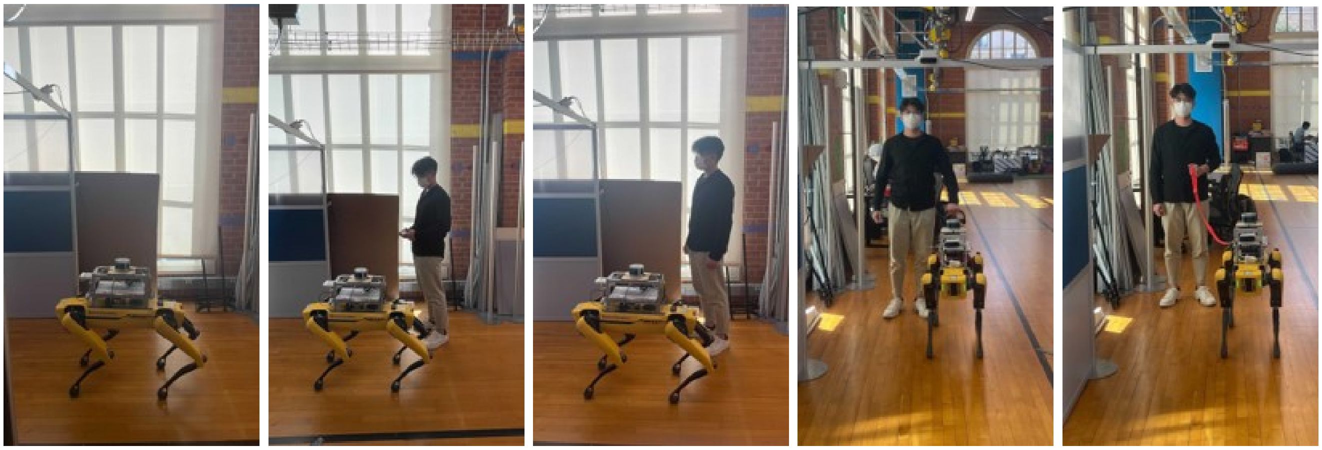
The questionnaire administered to study participants between trials is based in part on the Godspeed Questionnaire [1]. It consists of the following questions presented as 5-point Likert Scales. “Rate your impression of the robot” from: “Machinelike - Doglike”, “Apathetic - Responsive”, “Unfriendly - Friendly”, “Remote-Controlled - Autonomous”, “Unconscious - Conscious”, and “Unsafe - Safe”. “The robot moved”: “Too Close - Too Far.” “The robot’s motion was”: “Erratic - Under Control.” “When I encountered the robot I felt” (“Strongly disagree” to “Strongly agree”): “Curious,” “Cautious,” “Calm,” “Excited.” “I would be comfortable seeing this robot” (“Extremely uncomfortable” to “Extremely comfortable”): “Walking in an office,” “Providing delivery services on campus,” and “Providing delivery services to my home.”

At the end of all five conditions, a final questionnaire is administered asking participants to compare conditions on a subset of the questions administered between rounds. The scales are: “Doglike,” “Friendly,” “Autonomous,” “Safe,” “Under control,” “Comfortable to get close to,” “Comfortable seeing walk around an office,” and “Comfortable seeing providing delivery services.”

V. Results

The results for questionnaires administered between trials yield few statistically-significant results. The scale “Remote-Controlled - Autonomous” is statistically significant by a one-way Analysis of Variances (ANOVA) ($F_{4,125} = 14.073$, $p < 0.001$). Using the Tukey post-hoc criterion, only contrasts against the “Remote-Controlled” (higher is more autonomous) condition are significant (all at $p < 0.001$;

[2] https://microsoft.github.io/Azure-Kinect-Body-Tracking/release/1.1.x/index.html



(a) Fully-Autonomous (b) Remote-Controlled (c) Companion (d) Leading (e) Guided

Fig. 3: The robot as outfitted for each of the five conditions in this study.

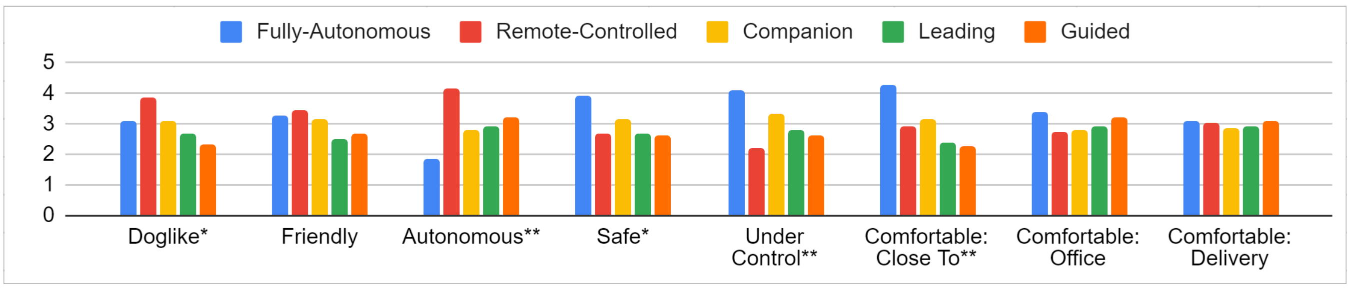


Fig. 4: Rankings across each metric in the final questionnaire administered to study participants. A lower rank means that the robot is perceived better on the corresponding metric. * - Sigificant at $\alpha = 0.05$, ** - Highly Significant at $\alpha = 0.01$

mean difference: "Fully-Autonomous" - 1.769, "Companion" - 1.846, "Leading" - 1.423, "Guided" - 1.615). The scale "Unconscious - Concious" is statistically significant ($F_{4,125} = 4.428$, $p = 0.011$). Using the Tukey post-hoc criterion, most of the contrasts against the "Remote-Controlled" (higher is more autonomous) condition are again significant (mean difference: "Fully-Autonomous" - 1.038, $p = 0.33$; "Companion" - 1.192, $p = 0.009$; "Leading" - 0.808, $p = 0.161$; "Guided" - 0.923, $p = 0.077$).

Results for questionnaire administered at the end of the study are mostly significant, however. For the end questionnaire, participants are asked to rank the conditions against each other. There is one small bug in the way that this ranking was administered, in that it is possible to (and participants did) give two conditions the same ranking. Rankings can be seen in Figure 4. Statistical significance is computed using the Friedman Test. From these results, it can be seen that the "Guided" and "Leading" conditions are viewed as the most "Doglike"; the "Fully-Autonomous" condition is seen as the most autonomous; and the "Remote-Controlled," "Leading," and "Guided" conditions are seen as the most safe. "Remote-Controlled" is seen as the most under control, but participants are most comfortable getting close to the "Guided" and "Leading" robots.

VI. Discussion

The results of this study indicate that by placing the robot contextually into different handler-canine roles that participants' perceptions of the robot on several important metrics can be changed. Importantly, it can be seen that pedestrians can be made to feel safer and more comfortable getting close to quadruped robots that are placed into traditional handler-canine roles, such as being walked on a leash or in service dog gear. It would take many study participants to extend this study to an inter-participant design, but this may help to increase the contrast in ratings between conditions.

This work serves as a starting point into more extensive research on quadruped social navigation that is in the planning phases, wherein there are plans to place quadruped robots into useful roles such as guiding the blind or doing jobs guided on a leash. These results indicate that there is the potential for quadruped robots to be well-received in these roles.

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