Embodied Encounters in the Forest: Human Interpretations and Sense Making of Robot Presence and Behavior

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Abstract

As robots move from controlled laboratory environments to real-world settings, it is increasingly important to understand how people perceive and respond to their behaviors in dynamic and uncontrolled contexts (e.g., forest), more specifically how the communication unfolds between robots and humans. This study investigates how humans interpret the gestural behaviors of a quadruped robot during a forest walk, aiming to understand how these interpretations shape their responses. Through thematic analysis of interviews with eight participants walking with the robot, we generated three key themes. Findings show that participants interpreted ambiguous movements meaningfully, guided by the robot's animal-like appearance and the surrounding context. Moreover, gestural communication facilitated subtle exploration, and lastly, non-intrusive exploration and interaction were shaped not only by participants' actions but also by their attribution of the robot's agency and intentionality. These results contribute valuable insights into human-robot interaction dynamics in uncontrolled outdoor settings.

CCS Concepts

• **Human-centered computing** → Empirical studies in HCI.

Keywords

Social Robots, Human-Robot Interaction (HRI), Human-Robot Communication

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1 INTRODUCTION

As robots transition from controlled laboratory environments to everyday settings, understanding how humans interpret and respond to robot behaviors in situ has become a central concern in human–robot interaction (HRI). Within HRI, communication often emerges through behavior, with robot actions functioning as communicative cues [1]. Previous research on communication between humans and robots has investigated different interaction modalities, including speech, sound, visual displays, lights, touch, and bodily movement [2], [3]. Non-verbal cues such as movement, gaze, orientation, speed, and pauses play a critical role in shaping how individuals anticipate robot actions, coordinate behavior, and allocate attention during interaction [4], [5], [6]. These embodied cues are particularly significant when explicit communication channels are limited or absent.

Zoomorphic robots, which incorporate animal-like forms and behaviors [7], have been extensively studied for their potential to support socially meaningful interaction. Studies with Aibo, a dog-like robot, demonstrate that physical characteristics such as fur, appearance framing, and dog-like behaviors can influence user engagement, bonding, and socially meaningful responses [8]. Likewise, animal-inspired movement and posture can serve as expressive signals, without verbal explanation [9], [10]. These interpretations depend on the robot's appearance and expectations, which shape intentions and agency [11], although findings are highly contextual and environment dependent. The majority of previous studies have been indoors in controlled settings, while dynamic and uncontrolled environments, such as forests, have rarely been explored. Forest offers a dynamic and uncertain interactive context, involving uncertain conditions and rich sensory input that strongly shape interaction [12]. For robots that communicate through their embodiment, these conditions can evoke behaviors that are less explicit and open to multiple interpretations. Previous work on robots in outdoor contexts suggests movement, positioning, and responsiveness as predictors of companionship and affective responses, especially during walks [13],[14]. Walking is a rich context

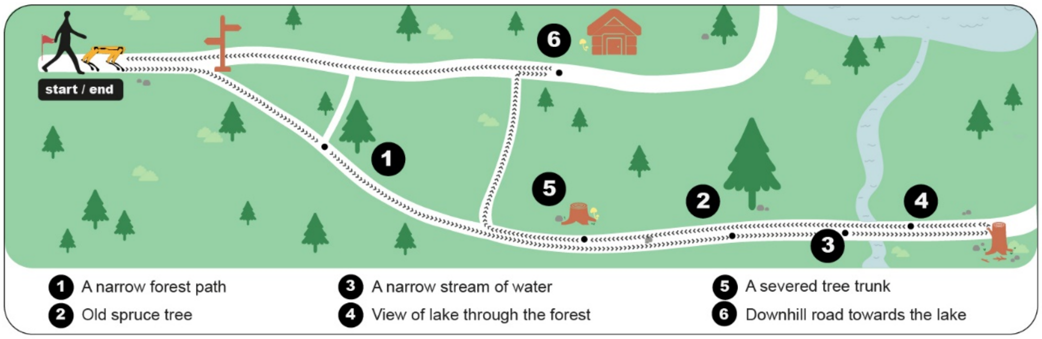

Figure 1: Visualization of the route with the six predefined stops.

for studying HRI, enabling reflection, exploration, and attentional shifts [15]. Moreover, there is a lack of studies that attempt to understand robots as they are, especially, from a more-than-human perspective [16]. This study addresses this gap by investigating how humans make sense of and respond to a zoomorphic quadruped robot in the forest.

We conducted a qualitative field study in which participants walked alongside Spot [17], a zoomorphic quadruped robot by Boston Dynamics, in a forest environment. The robot communicated exclusively through embodied movement, requiring participants to rely on bodily cues to interpret its actions. Therefore, this research attempts to address the following questions: *How do humans interpret the robot's gestures and body movements during a forest walk?*, and *How do these interpretations shape their responses?* We provide empirical insight into embodied zoomorphic communication and demonstrate how a robot's embodied communications are interpreted, revealing mechanisms of meaning-making in dynamic social interactions. These findings contribute vital insights into HRI dynamics in an uncontrolled dynamic setting, which might pioneer future design of robots as influential beings in the human social scene.

2 METHOD

2.1 Setting

The study was conducted on forest walking trails (Fig. 1), selected for their varied natural features, including uneven terrain, trees, minor elevation changes, a lake, and a narrow stream. The route formed a semi-loop, starting and ending the walk at the same spot. The numbered locations (1–6) in Fig. 1 indicate the interaction points, where the robot stopped and performed simple gestural movements. These behaviors designed by taking inspiration from natural dog behavior, and were natural to the robot in the study [18].

2.2 Participants

Eight university-affiliated participants (six women, two men; aged 18–35) were recruited via intranet and campus postings. All reported visiting nature at least twice a week, with two visiting three to four times weekly. Five had prior experience with non-home appliance robots, but none had walked with a robot before. One participant owned a dog and another a cat. All provided informed consent and received a small gift (up to 7 EUR) for participation.

2.3 Protocol

Each participant completed two walks along a predefined forest trail, during which the robot's engagement behavior varied between conditions. The robot either actively interacted with the surroundings by stopping at six predefined points to perform short movement sequences (active) or walked continuously without stopping or interacting (passive). For each participant, the robot's role remained constant across both walks, either leading from the front (leader) or following from behind (follower); participants were informed of this role at the start of each walk. The purpose of using different conditions in the experiment was to diversify the interactions, which allowed us to explore different communication attempts and sense-making processes. Condition order was counterbalanced, and roles were not switched within a session. During active conditions, the robot performed six stop-point behaviors. At Stop 1, it swept its body and head left and right, then tilted up and down, took a few short steps, and tilted its body up and down again, framed as the robot appreciating unique natural elements. At Stop 2, it tilted up and down and swept side to side with a lateral lean, intended to convey the robot analysing an old spruce tree. At Stop 3, it rotated slightly left and right, then tilted up and down twice, framed as appreciating a stream. Stop 4 involved lifting the body and head while shifting left and right rapidly twice, framed as appreciating a lake. At Stop 5, the robot rotated left and right and lifted its body, framed as analysing a natural element. At Stop 6, it swept side to side slowly while slightly lifting the body to the right, framed as appreciating nature. After each stop, the robot reoriented toward the path and resumed walking. In passive conditions, the robot followed the same route and walking flow without performing these movements. Each walk lasted approximately 8–15 minutes, depending on the condition.

Two researchers followed the interaction from a distance of approximately 3 meters. In the leader condition, the robot was operated using a Wizard of Oz approach [19] by one of the researchers via a tablet controller, following a predefined script; behaviors were not responsive to participants, and stop points and gestures were executed consistently across all active-condition trials. In the follower condition, the robot autonomously followed the participant using a wearable QR marker at the waist. The second researcher accompanied the walk to document observations. After completing both walks, participants took part in a semi-structured interview. Some of the key questions included: "*How was the communication between you and the robot?*", "*How did you respond to the robot's behavior during the walk?*", and "*How did you interpret the robot's movements?*". Contextual observations from the walks informed follow-up questions.

2.4 Data Analysis

The interviews were recorded and subsequently transcribed using the MS Word Dictation Tool, then reviewed to correct transcription errors. MAXQDA was used for coding, by the first author, following a reflexive thematic analysis approach [20]. The codes were then reviewed by the second author. Initial codes were exported to Mural and clustered using affinity diagramming [21] through a collaborative process involving both researchers to generate and iteratively refine topics and subtopics. These were merged into higher-level themes reflecting broader patterns across the data. This process resulted in three major themes.

3 Thematic FINDINGS

3.1 Theme 1: Interpreting Animal-like Communication

Participants interpreted the robot's movements through familiar animal-like cues, often comparing its gestures and motion patterns to those of a dog. P8 (follower condition) described the robot's scanning movements, pausing and tilting its body up and down and side to side, as animal-like and informative for understanding what it was attending to: *"I noticed quite animal-like body language, the way it moves, the way it looks down and up, and kind of tries to perceive the environment."* These cues helped participants make sense of the robot's behavior and anticipate its actions, reflecting a tendency to connect with life-like forms, consistent with the concept of biophilia [22]. These interpretations may have been further shaped by the robot's animal-like appearance, which made its movements more readily comparable to familiar dog-like behavior.

Similarly, P1 (follower condition) described the robot's stopping and reactions as resembling those of a dog responding to environmental stimuli: "*I think it's just trying to mimic an actual dog. Like if I'm walking with my dog, and it sees a squirrel, it will start doing something, or like if it notices some sound, it will stop.*" This suggests that participant's sense making was guided more by the robot's animal-like appearance and behavior than by its status as a machine, consistent with prior work showing that people often respond to robots based on familiar cues rather than their ontological status [11]. However, the same participant described a moment when the robot's behavior deviated from what they expected: "*Normally it would look, it would point its camera at me and then start following me. But this time it was just doing its own thing and like spinning, going up and down and doing like random movements*". In such moments, when the robot stopped unexpectedly or moved in unclear ways, participants interpreted the behavior differently, some described it as distraction, confusion, or loss of attention, while others framed it as independent actions or a malfunction.

Analysis shows that ambiguous moments did not undermine interaction. Instead, animal-like interpretations became especially important when the robot's behavior was unclear. Pauses, scanning, and exploratory movements aligned with expectations of how animals behave in natural environments, where shifting attention and unpredictability are common. However, when movements did not resemble familiar animal behavior, participants were more likely to interpret them as malfunctions or random errors, causing confusion.

3.2 Theme 2: Robot-mediated Attention in an Unfamiliar Environment

Participants frequently interpreted the robot's body movements, gaze, orientation, and stopping behavior as cues that oriented their attention toward elements of the surrounding environment, with the robot's behavior subtly shaping what became noticeable during the walk. P4 (follower condition) described how the robot's stopping behavior created an opportunity for environmental noticing: "*I was so focused on going and finishing the path, but then actually, when stopping, it was the first moment when I could notice the river flowing by and making sounds, and then we could move on.*" This illustrates how robot's pauses redirected participants' attention away from task-oriented walking and towards sensory aspects of the environment. The robot's stopping behavior did not interrupt the interaction but instead structured moments of awareness and reflection, subtly mediating how the forest was experienced during the walk.

P7 (leader condition) also described interpreting these pauses as intentional invitations to attend to something specific, even when the object of attention was initially unclear: "*Yeah, I stopped, and I thought it was like showing me something that I needed to look at it, so, I took it as a sign to look for something.*" This response might suggest that participants did not require the robot to indicate a clearly identifiable object through explicit signals such as pointing, lights, or sounds in order to treat its behavior as meaningful. Instead, the robot's bodily movements themselves, such as stopping and moving its body up and down as if scanning, were sufficient to trigger exploratory attention, with participants actively searching the environment to make sense of what the robot might be attending to. In this way, the robot's behavior potentially functioned less as explicit direction and more as an invitation to engage in sense-making.

However, attentional mediation was not automatic or unconditional. As P3 (leader condition) noted, while the robot's gaze toward dynamic elements such as flowing water felt meaningful, similar behaviors directed at less salient areas did not always invite attention: "*When Spot looked at the water, it's nice to watch. But in some locations where Spot looked at just nearby forest, I wouldn't say that there was any kind of point... it wouldn't get any attention for me*". This indicates that participants assessed the robot's cues against their own expectations of what was worth noticing in the environment.

These observations show that robots might function as an attentional mediator rather than a director of attention, proposing points of interest that participants actively interpreted, accepted, or chose to disregard. This mediation relied on participants' engagement with the environment, as they evaluated whether the robot's cues aligned with what they found meaningful in the forest. This indicates that attentional influence might have emerged through ongoing interpretation shaped by the interaction dynamics and settings.

3.3 Theme 3: Accommodating the Robot's Intentional Behavior

Participants often allowed the robot to act independently, across both leader and follower conditions, suggesting that they did not treat the robot as something to be continuously guided, but as an autonomous walking partner with its own intentions. Several participants described intentionally avoiding intervention while the robot was moving or scanning the environment, expressing a reluctance to disrupt what they perceived as the robot's intentionality. P8 (follower condition) framed this as giving the robot freedom, drawing a parallel to how one might walk with a companion rather than manage a tool: "*I kind of wanted to give it the freedom to do stuff. I didn't want to meddle and interfere.*" This suggests that participants likely refrained from intervening because the robot was understood as an autonomous companion rather than a tool to be managed.

This stance was especially evident in moments of ambiguity. Rather than trying to resolve unclear behavior, participants often accepted uncertainty as part of the interaction. As P8 (follower condition) explained: "*I didn't try to analyze it too much... especially if it's not a behavior that has a very clear pattern.*" Here, non-intervention reflected a choice not to impose meaning or control, as long as it did not suggest a specific meaning, allowing the interaction to continue without demanding clarity. In some cases, this resulted in participants waiting for the robot to complete actions. P3 (leader condition) described remaining idle while the robot finished an action: "*It's basically waiting, like I'm just waiting that we keep going on.*" Waiting then became a way of coordinating with the robot, even when its behavior was not immediately meaningful.

Overall, these findings indicate participants' willingness to let the robot do its own thing was shaped by a situated attribution of agency, rather than by disengagement or confusion. In this way, interaction was coordinated not only through participants' actions, but also through deliberate non-action, reflecting a companion-like relationship in which the robot was treated as having its own ongoing activity and agency.

4 DISCUSSION AND FURTHER DIRECTIONS

4.1 Insights and Contributions

Our analysis shows that participants interpreted ambiguous bodily movements meaningfully, relating them to the robot's zoomorphic form and the context (Theme 1). Prior work on zoomorphic robots has shown that bodily expressions are interpreted in relation to the robot's appearance, as seen in studies where users rely on animal-like form to make sense of gestures and movements [7]. Additionally, previous work on zoomorphic gestural communication shows that people can identify predefined meanings of a quadruped robot's gestures in controlled indoor settings by relying on its appearance [1]. Our findings align with this line of work while further showing that participants relied on the robot's animal-like appearance to make sense of ambiguous bodily movements in an outdoor context, where meaning emerges through the combination of form, ongoing activity, and environment. This suggests that meaning in zoomorphic human–robot interaction can emerge through situated sense-making, rather than solely through the decoding of intended signals.

Moreover, participants responded to the robot's bodily gestures without explicit instruction, allowing attention to be guided in a subtle and non-intrusive way during a walk in the forest (Theme 2), extending previous speculative work on companion robots in outdoor contexts [23]. Studies on walking outdoors with robot dogs have reported that participants perceived the robot's movements as ambiguous, leading them to suggest that a walking companion robot should clarify its intentions [13]. However, we found that, in a forest setting, ambiguity did not necessarily lead to frustration or demands for clarification. This suggests that in rich outdoor contexts, implicit gestural communication can support exploratory and companion-like interaction without requiring continuous feedback. We further noticed that participants accommodated the robot's independent behavior, tolerating ambiguity and self-directed movement (Theme 3), which created space for more fluid and natural interaction, extending previous work on walking with robot dogs outdoors [13], where participants perceived autonomy and a "mind of its own", creating a sense of companionship with the robot.

These insights contribute to HRI by informing the design of zoomorphic robot communications, suggesting that meaningful interaction can emerge without directive communication. The findings extend existing accounts of robot communication by framing it as an emergent, situated process in which meaning is co-constructed through interaction rather than decoded from signals. Across themes, participants' sense-making mechanisms were observable in how they oriented, paused, and adjusted their movements in response to the robot's gestures. These behaviors reveal design features, including the robot's body tilts, sweeps, rotations and stop timing, which shaped how participants interpreted its actions. This study provides empirical, in-situ evidence from a real-world walking scenario, complementing laboratory-based and speculative work, and enriching current understandings of zoomorphic HRI in natural and dynamic environments.

4.2 Limitations and Future Work

Our study focused on a small group of university-affiliated participants; findings may change for older adults or those less familiar with technology. Moreover, our focus was on short-term interaction; longer studies could examine how perceptions and engagement evolve as the novelty of walking with a robot changes over time. Another limitation is that although interaction conditions were counterbalanced, order effects may have occurred because participants walked the same path twice, which may have influenced their experience during the second walk. Future work might explore new patterns of robot bodily movements, along with additional modalities, such as sound, light, or verbal cues, to reveal how multimodal communication shapes interaction within a forest context.

5 CONCLUSIONS

This study shows that zoomorphic robots can enable embodied, non-directive communication during shared walking in natural, uncontrolled environments. Participants interpreted the robot's movements as communicative when they aligned with familiar animal-like behaviors, with appearance playing a central role in supporting meaning-making. Rather than directing attention explicitly, the robot's gestures facilitated subtle, open-ended exploration. Interaction was coordinated not only through human action but also through deliberate non-action, as participants allowed the robot to act independently, reflecting a companion-like orientation. Although based on a small sample, these findings offer initial empirical insights into how form, movement, and context shape human–robot interaction in forest settings, highlighting the potential of zoomorphic gestural communication to support social, exploratory, and attentional experiences during shared outdoor walking.

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