# Design and Evaluation of Touch-Based Expressive Movement for Abstract Robotic Platforms

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*Abstract*— **This preliminary study explores whether a featureless cube could be perceived as a social actor the moment it initiates a nudge. The exploratory research investigates the potential of physical nudges using a custom cube-shaped robot equipped with a Stewart-Gough platform and an omnidirectional base. Utilizing animation principles, the study gathers initial insights into how a small sample of users perceive intent and agency during a touch-based interaction with a non-humanoid form. Initial observations across situated and isolated conditions indicate that while specific emotional intent is difficult to decode in a vacuum, these signals become more legible through the co-constructed meaning of a live encounter. In these situated contexts, physical contact appeared to heighten the attribution of social presence and seemed to reduce negative user affect. These findings demonstrate that intentional touch warrants further investigation as a medium for social interaction, suggesting that minimalist robotic forms can foster relational significance without relying on anthropomorphic mimicry.**

## I. INTRODUCTION

Communication in Human-Robot Interaction (HRI) is no longer restricted to verbal or linguistic exchanges. Modern social robots rely heavily on non-verbal signals to support engagement. The expressiveness of a robot's body, even in abstract forms, dictates how humans perceive its social presence. This occurs because non-verbal cues often convey more significant meaning than language alone [1]. Within this landscape, body movement and specifically touch represent an underexplored interface for interaction.

Inspired by animation principles, this research explores how geometric simplicity can facilitate affective communication through timing, rhythm, and gentle physical contact. Such interactions demonstrate that expressive, embodied communication does not require anthropomorphic features. This is evident in how bystanders routinely attribute intent and emotion to the navigation of strictly functional machines, like vacuum or delivery robots. Ultimately, these dynamics underscore the significant, untapped communicative potential of robot-initiated touch.

While touch is gaining traction in HRI, majority of research focuses on human-initiated contact or tactile sensing. Robot-initiated touch remains largely unexamined. Existing studies largely rely on humanoid or zoomorphic forms. Consequently, expressive and intentional touch from abstract, non-humanoid robots remains a primary research gap.

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Because touch is a non-verbal channel, relying solely on humanoid robots can be limiting. Non-humanoid robots – ranging from abstract spheres to instrumental objects – have successfully conveyed social gestures in prior work [2]. These findings align with the classic work of Heider et al. [3], which demonstrated that people attribute social meaning to the simple motions of geometric shapes. According to Anderson-Bashan et al. [4], abstract designs offer greater design freedom, lower costs, and avoid the Uncanny Valley effect by bypassing unrealistic human-like expectations [5].

Saunders and Gemeinboeck [6] are strong advocates for abstract social robotics, arguing that moving away from pet-like morphologies allows for the study of interaction in its purest form, free from anthropomorphic bias [6], [7]. They propose that social agency emerges through the encounter itself rather than through human resemblance. Building on this foundation, this study investigates how non-humanoid robots can use physical nudges – gentle pushes that function as social cues – to communicate affect and intent. We aim to address how people perceive and respond to these robot-initiated cues, the extent to which agency is attributed to the machine, and whether such encounters influence the user's emotional state. For this purpose, a custom cube-shaped robot was developed using a Stewart-Gough platform and an omnidirectional base to analyze the role of intentional contact in shaping social perception.

This work provides a more detailed account of the research previously presented in ”The Nudging Machine: Exploring Expressive Touch-Based Movement for Abstract Robots” [8]. While the core study remains consistent, this version offers a more robust presentation of the technical frameworks that were abbreviated in the prior format.

## II. BACKGROUND

This section establishes the theoretical and empirical foundations of the study.

### A. *Theoretical and Functional Groundings of Touch*

Touch is the most fundamental medium for environmental interaction, developing before other senses and playing a vital role in human cognition and emotion [9], [10]. In nonhuman primates, tactile behaviors such as grooming maintain social hierarchies, reduce stress, and build alliances [11]. Dunbar's social brain hypothesis [12] connects these behaviors to the evolution of social cognition and large-scale brain development. Evolutionarily, primate hands transitioned from locomotory tools to instruments for nuanced communication [13], marking touch as a dual-purpose emotional and functional tool.

Despite its communicative potential, touch is frequently underexplored due to its methodological complexity [10]. Specifically, the nudge, a localized, active touch of minimal duration, has been largely ignored in HRI.

### B. Motion and Minimal Expressiveness

Physical contact is inherently mediated by movement dynamics such as rhythm and trajectory. Non-verbal cues frequently occur at the unconscious level, proving an honest channel for communication.

**Kinesics and Expressive Movement** Hoffman et al. [14] introduced robotic experience companionship, demonstrating that responsive, rhythmic body movements can strengthen social presence. The ELEGNT framework [15] similarly integrates expressiveness into functional movement for non-biomimetic robots, finding that "moving with feeling" increases relatability. Research on minimal robots, such as robotic footstools [2] or abstract spheres [4], confirms that even object-like forms can coordinate joint action through kinesics. Additionally, Performative Body Mapping (PBM) provides a method for developing motion vocabularies grounded in embodied performance, emphasizing relational aesthetics over anthropomorphic features [6], [16].

**Proxemics and Robot Appearance** Humans generally prefer robots to maintain socially accepted distances, and violating these boundaries can lead to psychological distancing [17], [18]. Conversely, strategic proximity can act as a clear social cue. Regarding appearance, while humanoid forms can facilitate rich communication, they risk the "Uncanny Valley" effect if behavior does not perfectly match form [19]. This underscores the need for congruence between a robot's physical aesthetics and its non-verbal behavior.

## III. Related Work

Existing research on touch in HRI is divided into two areas: human-initiated and robot-initiated touch. Complementary work has focused on developing tactile sensors and establishing acceptable practices for physical HRI [20], [21].

### A. Human-initiated Touch

Human-initiated touch is a primary channel for conveying affection to robots [22]. Much of this research utilizes the Paro seal robot, showing that tactile interaction can reduce pain perception, alleviate stress, and improve mood in therapeutic settings [23], [24]. Studies involving the Nao humanoid also explore how humans communicate affect through touch and how they perceive robots that react to such contact [25], [26].

### B. Robot-initiated Touch

Active touch initiated by robots remains less explored, falling into three main areas: instrumental touch, affective soothing, and perception studies.

**Instrumental and Affective Touch** Functional touch studies, such as those involving robotic nurses or navigation assistants, show that perceived intent significantly influences human response [27], [28]. Affective touch, including robotic hugs and hand-holding, has been found to increase trust and facilitate emotional calming [29], [30]. Additionally, robotic touch can be used for behavior nudging to increase compliance or inhibit senses of unfairness [31], [32].

**Perception and Context** Proactive robotic touch can influence perceptions of a robot as dependable rather than purely machine-like [33]. Studies vary touch type and duration to convey specific emotions, such as brief pats for happiness or gentle holds for sadness [34]. Recent findings highlight that the interpretation of these gestures is deeply shaped by the surrounding situational context [35].

### C. Research Question

A nudge is a social gesture that does not require a humanoid form, making it a prime candidate for studying communication through abstract movement. This study aims to examine how abstract robots can communicate intent and social presence through nudges. Specifically, it asks: *How are affect, intent, and agency perceived in nudging gestures initiated by a non-humanoid robot?* By decoupling interaction from mimicry, this research seeks to understand how simple, embodied cues can elicit rich social meaning.

## IV. Design and Implementation

The development of the robotic platform was driven by the need to understand how an abstract morphology can still initiate meaningful physical contact.

### A. Structural Composition and Kinematics

To deliver localized and expressive nudges, the robot required a physical form that was simple and mechanically capable. While curved shapes might limit the precision of a touch, a polyhedron provides flat surfaces and defined edges; consequently, a 25 cm cube was chosen to balance hardware space with an easily projectable abstract form.

The internal mechanism was designed to produce fine-grained gesture control. The core assembly features a 6-DOF Stewart-Gough parallel manipulator to actuate the cubic shell, allowing for expressive tilting and translation, while an omnidirectional base with four Mecanum wheels provides the necessary global mobility for precise approach (see Figure 1). To ensure that touch gestures remained consistent across different participants, a front-facing HC-SR04 ultrasonic sensor was integrated, effectively defining a "front" side on an otherwise symmetrical body. The static robot appears as a neutral, white object, which allows its social character to emerge entirely through its kinetic behavior.

### B. Motion Capture and the Animation Interface

Generating organic movement for a non-humanoid form requires an artistic, performance-based methodology rather than traditional programming. To achieve this, we developed a system that records and replays high-fidelity trajectories captured directly from an expert animator. The animator manipulates a scale model proxy over a ChArUco tracking

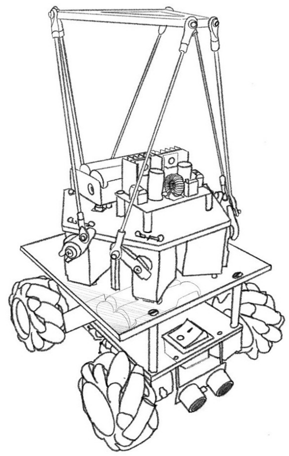

Fig. 1. **Robotic Hardware.**Technical drawing of the robot's internal design, showing the Stewart platform structure mounted on an omnidirectional wheeled base.

board (see Figure 2), while directing an assistant to move the base via a joystick. An integrated camera and motion sensors capture unconstrained, natural gestures. This pipeline yields a 10-value data stream for the platform and base, enabling the robot to replicate the animator's organic performance with high repeatability in real time.

### *C. The Expressive Database*

The movement library was mapped across a design space pairing functional goals with emotional states. Social intents included seeking attention, claiming space, and seeking comfort (animal-inspired), alongside a "no-intent" functional baseline. To minimize confusion, we selected five distinct targets maximizing distance in the valence-arousal space: excited, content, angry, sad, and a neutral baseline. Aligning with Bossema et al. [36], the neutral baseline used linear global locomotion without local platform transformations.

The library was developed during five iterative sessions with a professional animator. First, we established technical parameters and drafted qualitative movement descriptions using Laban Movement Analysis. To ensure descriptive rigor, these profiles were cross-referenced with formal terminology using a Large Language Model (LLM). This step functioned as an active evaluation tool: where the LLM flagged inconsistencies, the animator was prompted to either defend their original kinetic approach or refine it based on their professional judgment. Next, we validated kinematic feasibility on the platform. The animator then refined the tactile feedback in real time against a researcher's arm, iteratively adjusting actuator force profiles to ensure the physical impact matched the designed emotional affect. The process yielded a finalized repository of 20 expressive movements.

## V. Evaluation

Perception within physical HRI is multi-dimensional, with factors like movement, and proximity contributing to how a physical contact is interpreted. Because these factors present challenges for experimental control, the study was split in two to balance ecological validity with analytical clarity.

**Situated Interaction:** A naturalistic encounter where the robot and participant negotiate a shared space for approximately three minutes. The interaction is designed to signal the robot's intent to move forward, prompting the participant to clear their arm from its path (see Figure 3). This phase explores the attribution of agency and the alignment of designed gestures with interpretations within a goal-oriented context.

**Isolated Gesture Evaluation:** A controlled phase where the participant observes five randomized gestures stripped of broader situational context. This part evaluates the legibility of specific animated nudges.

### *A. Participants and Materials*

We recruited 24 participants (primarily students, 58% female, 42% male). The demographic screening included self-reported neurodivergence and touch sensitivity, allowing the study to account for individual differences in how social presence is perceived.

The experiment was conducted in a co-located, tabletop environment designed to facilitate touch negotiation. Positioning the participant's forearm along a designated path isolated the micro-dynamics of tactile gestures by eliminating confounding variables from macro-scale spatial navigation; constraining touch-free movements ensured a consistent level of influence across trials.

All interactions were recorded for retrospective think-aloud protocol, and data was captured via a tablet-based Qualtrics survey. Software and firmware used for robot control are available as supplementary material[1]

### *B. Procedure*

The procedures for both phases were designed to elicit and capture reflections on the robot's perceived intentionality.

**Situated Interaction.** To begin the session, the researcher instructed the participant to place their arm on the designated line and engage with the robot as naturally as possible. Following Sirkin et al. [2], a Wizard-of-Oz setup was implemented. The researcher monitored a live camera feed to navigate the robot to the gesture initiation point. The interaction involved an escalation of three nudges: an initial 'content' attention-seeking gesture, followed by two space-taking gestures that increased in arousal while decreasing in valence. Following the sequence, participants were interviewed about the robot's goals and perceived internal state, complemented by pre- and post-interaction Positive and Negative Affect Schedule (PANAS) and Robotic Social Attributes Scale (RoSAS) scales to measure affective shifts.

**Isolated Gesture Evaluation.** Here, participants were exposed to five randomized trials from a pool of 20 affect-intent pairs. For each gesture, participants identified the robot's intent and assessed its affect using an adapted Self-Assessment Manikin (SAM) scale. To ensure the rigor of the

[1] `https://github.com/kaminatic/9-DOF-Mobile-Robot-Control-Stack`

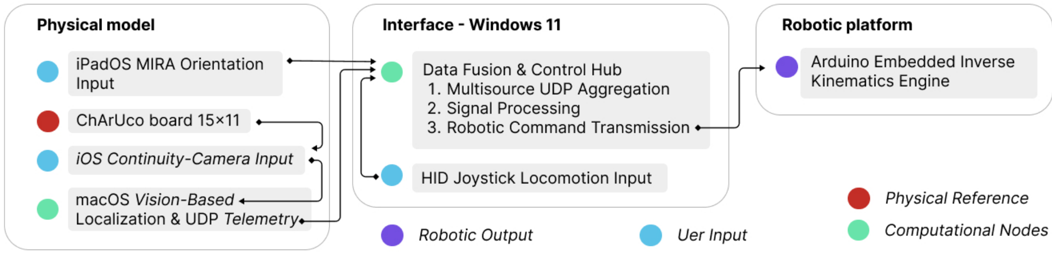


Fig. 2. **Motion Design System Architecture Overview.** Components are color-coded by function: blue denotes user-controlled input devices for orientation and locomotion; red indicates the physical tracking reference; green represents computational processing layers for data fusion and signal processing; and purple identifies the final robotic output. This configuration enables the real-time translation of physical model manipulation into expressive trajectories.

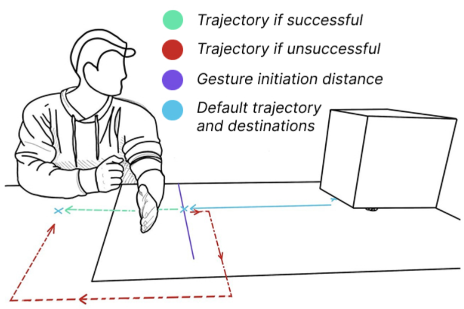


Fig. 3. **Situated Interaction Setup.** For the isolated observation phase, the physical setup remained identical, but the protocol shifted: the robot started at the gesture initiation point while the participant acted as a passive observer of the robot's movements

intent-recognition task, we included two distractor options to verify if participants could distinguish specific social nudges from general space-related navigation. Beyond the provided multiple-choice selections, participants had the option to describe the intent in their own words.

## VI. RESULTS

The study findings describe how participants decoded expressive nudging in both situated and isolated conditions.

### A. Situated Nudge

In the situated condition, participants consistently framed the robot's behavior through familiar social categories, frequently comparing the device to a puppy or a young child.

**Intent and Emotion recognition** While approximately half of the participants correctly identified the intended navigational goal during interviews, only one-third did so in written responses. Interpretations often shifted dynamically; for example, P17 initially perceived the robot as "playful" before realizing it was "trying to go around" an obstacle. Participants noted a behavioral arc, describing the robot as moving from "cautious" to "frustrated" as its attempts to pass were blocked. Mentions of aggression were common but were notably qualified as non-threatening or "cute".

**Social Attributes and Agency** On the RoSAS, the robot scored highest in "interactive" and "social" traits (6.7–7.2/9). A surprising finding was that neurodivergent participants perceived the robot as significantly warmer than neurotypical participants ($p = .0317$). Due to the size of the participant pool, this is a preliminary trend that should be treated with caution. Agency attribution was predominantly moderate to high. Ten participants attributed high autonomy, describing the robot as "unpredictable, alive, and organic". Conversely, only one participant denied its agency. Interestingly, P21 noted that the sense of "sentient attachment" was specifically triggered by the physical contact.

**Affective impact** Interaction led to a significant increase in overall emotional state ($p = .005$), primarily driven by a statistically significant reduction in negative affect ($p = .0014$). This gain was more pronounced in participants with extensive prior robotic experience ($p = .022$).

### B. Isolated Nudge

When gestures were decontextualized, "strict" accuracy for exact intent-emotion recognition was 0%, highlighting the difficulty of interpreting touch in a vacuum.

**Intent Grouping and Confusion** Overall, strict intent accuracy was low (22.5%), but grouping intents into broader "Socially-driven" (seeking attention/comfort) vs. "Navigation-driven" (taking space/guiding) categories increased accuracy to 43.3%. The "no-intent" category was almost never recognized. A moderate correlation emerged between perceived competence of the robot and intent accuracy ($r = .50$), though this effect did not survive correction.

**Emotion and Dominance** Recognition of specific emotions remained weak, with responses clustered near neutral. Sadness was most accurately identified (54.2%), while excitement and anger showed the largest deviations. Dominance emerged as a dimension independent of robot design; it correlated positively with interpreted arousal ($p = .005$).

**Calibration and Confidence** Participants exhibited overconfidence in interpretations, with mean confidence exceeding accuracy by 0.2–0.3. Calibration analyses showed that confidence did not correlate with performance; participants were just as confident in incorrect guesses as correct ones. Confidence was also interrelated across all dimensions.

## VII. DISCUSSION

This study examined how affect, intent, and agency are perceived when a non-humanoid robot initiates physical contact. Our findings suggest that while designers can encode specific signals into motion, the meaning of a nudge is a co-constructed phenomenon that emerges through the dynamic of the encounter [37]. Embodiment theory suggests that impressions arising from physical interaction are inherently unpredictable [38]; the cube's agency was not merely 'delivered' to the participant but was brought into being through the relational dynamics of the space.

The robust attribution of agency to a minimal, abstract form is a primary outcome of the study. RoSAS ratings positioned the robot as a warm, competent, and emotional agent, despite its lack of a face or voice. Strikingly, only one participant denied the cube autonomy, reinforcing observations that minimal kinetic cues evoke animacy [3]. Most participants adopted a "moderate autonomy" frame, reconciling the machine's programmed nature with its perceived "organic" responsiveness.

While the small sample size limits generalizability, preliminary trends suggest that a participant's cognitive profile may act as a perceptual filter. Specifically, self-reported neurodivergent participants tended to rate the robot as warmer than neurotypical ones. Although exploratory, the trend highlights a less explored methodological direction: tracking neurodiversity as a broad self-reported measure to better understand how people with varying psychological profiles attribute intent and emotion.

This complexity in perception is evident in the sharp divide between situated and isolated conditions. In the interaction phase, half of the participants identified the pragmatic navigational goal, whereas in the isolated task, recognition was low. This suggests that in situated touch, social meaning is immediately salient, while pragmatic intent requires reflective elaboration. Our results complement functional robotics research [27] by showing that without prior framing, humans tend to default to a social interpretation of an abstract form.

In the isolated condition, participants struggled with fine-grained goals but were more successful at identifying coarse categories, such as social versus navigational goals. Interestingly, the "no-intent" nudges were almost never identified as accidental; the absence of context left participants with no cues to treat contact as unintentional, leading them to project social meaning even onto design baselines.

The gap between what participants felt and what they accurately decoded is illuminated by our analysis of dominance and confidence. Dominance impressions did not track with the robot's designed valence or intent; instead, they correlated strictly with perceived arousal. This implies that participants inferred dominance from the intensity of the nudge rather than the direction of the gesture. Furthermore, our calibration analysis revealed a systematic overconfidence: participants' mean confidence exceeded accuracy by 0.25 on average. Because confidence ratings were highly interrelated across dimensions, participants may not have been decoding specific signals, but were instead experiencing a general perceptual certainty born from their internal narrative.

This trajectory of narrative-building can be found in the affective trajectories reported by participants, who described an emotional shift from shy and cautious to assertive and frustrated. This mirrors the designed behavioral progression, confirming that perceived emotion is shaped by the sequential build-up of actions [35]. While isolated recognition was poor, sadness emerged as the clearest non-neutral state, perhaps resonating with the "cuteness" of the cube. Perhaps most significant was the qualitative reflection on the "sentient attachment" formed through touch. The physical nudge "breaks a barrier" that movement alone cannot, illustrating that touch uniquely heightens the perception of social presence.

A key limitation lies in the methodological tension between isolating touch and preserving its meaning, which impacts the "legibility" of the robot's intent. While our structured tabletop baseline ensured analytical rigor, stripping context in the isolated scenario may have left participants with insufficient cues to interpret the signals. Conversely, the situated interaction makes it difficult to decouple environmental influences from the tactile gestures themselves.

Furthermore, our use of a researcher-led Wizard-of-Oz protocol introduces behavioral variability and operator dependency, blurring the boundary between the robot's agency and that of the human-in-the-loop. To isolate tactile expressions, non-touching movements were strictly constrained to linear trajectories; however, future work would benefit from engaging motion experts to guide these spatial behaviors as well. Finally, given our small, largely WEIRD participant pool, broadening the demographic scope is essential. Because gestures are culturally inscribed techniques of the body [38], individuals from different backgrounds may interpret the legibility of these tactile interactions differently.

Deploying a non-humanoid robot in dynamic, unconstrained real-world settings introduces a compelling trade-off. While ambient noise and unpredictable paths might diminish a user's sensitivity to subtle tactile cues, real-world environments offer rich situational context and functional "priors" that naturally assist humans in decoding spatial intentions. Future studies should transition these baseline tactile gestures into these unconstrained environments to evaluate this interplay between ecological noise and contextual priors.

Alternatively, touch could be studied in complete isolation by depriving participants of sight and other contextual cues. Such blinded interactions necessitate heightened ethical standards and rigorous safety protocols, as the loss of visual control significantly increases participant vulnerability.

Beyond environmental manipulation, future evaluations should compare touch-based scenarios directly with no-touch baselines to measure the specific social weight of physical contact. It would also be valuable to investigate intentionality bias by comparing interpretations when participants are told the robot is moving autonomously versus being controlled by a human operator. Such a study could highlight how pre-existing robotic anxiety factor shapes the encounter. Lastly, the robot's material properties could be manipulated to determine how these physical parameters can be engineered to bridge human expectations with robotic signaling.

## VIII. CONCLUSIONS

This pilot study offers tentative evidence that robot-initiated touch may serve as a medium for establishing social presence and agency, even in the absence of humanoid or zoomorphic features. By utilizing a minimal cubic form, our exploration suggests that simple physical nudges can elicit social interpretations and a sense of attachment from users. While the results highlight the difficulty of communicating fine-grained emotions through touch alone, the broader interaction hints that physical contact could heighten the relational bond between human and machine. Ultimately, this study serves as a proof of concept, indicating that expressive movement and tactile engagement warrant further investigation as alternatives to anthropomorphic mimicry.

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