

# Non-Humanoid Robotic Communication: A Cube's Expressive Movements

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**Abstract** – This study investigates how a simple cubic robot conveys basic human emotions through motion, offering insights into emotion expression in abstract robotic design. The study builds on the six basic emotions as proposed by Ekman, which include happiness, sadness, anger, fear, disgust, and surprise. The research examines how movements and their movement characteristics, such as direction, rhythm, and speed, contribute to emotional perception in human-robot interaction (HRI). Thirty undergraduate participants engaged in an exploratory, mixed-methods study where cube movement patterns were created and interpreted in a controlled setting. Results revealed that emotions such as happiness, anger, and sadness were more easily recognised. At the same time, fear, disgust, and surprise showed lower clarity scores, indicating challenges in conveying complex emotions through a geometric form. The study highlights the role of perceptual ambiguity and symbolic neutrality in fostering creative motion strategies and underscores the value of combining quantitative and qualitative insights. Findings suggest that basic geometric forms, such as cubes, can support emotional communication in robotics. However, different shapes and motion semantics may require further attention in future studies to explore them properly, thereby making the communication of simple forms more expressive.

**Keywords:** Human Emotions; Geometric Forms; Human-Robot Interaction (HRI); Non-Humanoid Social Robots; Robotic Motion

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## I. Introduction

Emotions are a fundamental aspect of human life and essential to effective communication. The ability of robots to express and interpret emotions is increasingly important in the field of Human-Robot Interaction (HRI). Research in robotics and emotions has experienced significant growth over the last thirty years (Savery & Weinberg, 2020). The majority of emotional expression in robotics has been explored using humanoid features (Gao et al., 2024; Rawal & Stock-Homburg, 2022). Heider & Simmel (1944) had demonstrated that individuals attribute emotions to basic inanimate objects, depending entirely on their movement patterns. Therefore, later, the studies began to examine the possibility of conveying emotions through non-humanoid robots and their forms (Novikova & Watts, 2014). Geometric forms in robotic design are efficient and minimal, but their effectiveness in conveying emotions through movement is understudied in HRI, requiring further exploration.

This study was conducted as part of a broader research project aimed at exploring the potential of emotionally expressive non-humanoid robots in the context of the role of form and motion in emotional communication. Within this study, only the cubic form was used to examine how well basic human emotions can be communicated through movement patterns. Ekman's (1992) categorical model of six basic emotions, which includes anger, disgust, fear, happiness, sadness, and surprise, was considered in the study. This model is the most widely used categorical emotion model in studies to date (Wang et al., 2021). The study aims to respond to the following questions:

- How effectively are emotions conveyed via cube movement?
- How accurately can the intended emotions be identified?
- What is the perceived relationship between geometric form movement and emotional expression?

This study provides insight into how geometric forms can enhance emotional communication. It aims to contribute to the growing body of knowledge in the field of nonverbal expression within HRI. The insights gained from this study will inform further research that explores various form combinations and advanced movement techniques.

## II. Literature Review

Based on Heider & Simmel's (1944) seminal work, Baldwin & Baird (2001) emphasise the inherent ability of humans to discern intention from dynamic actions, even with the absence of human-like features.

Hoffman & Ju (2014) argue that movement is an essential element of emotional expression in the design of social robots, especially if facial expressions are absent. Similarly, Law et al. (2021) confirm that the movement style of non-humanoid robots largely shapes their emotional perception.

A study on the Greeting Machine by Anderson-Bashan et al. (2018) suggested that abstract robotic forms with no specific metaphor could effectively communicate social intentions through basic

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non-verbal cues. Erel et al. (2019) highlight the significance of movement semantics in HRI by arguing that all robotic movement, regardless of form, is inherently perceived as social. Consequently, when properly designed, even a cube-controlled movement could be used as a medium for emotional expression.

Cubes were identified as ideal for studying emotion through movement due to their perceptual ambiguity, symbolic neutrality, geometric simplicity, and visual stability, which reduces shape biases and stimulates cognitive perception. (Costa & Bonetti, 2016; Guberman, 2023; Groux, 2015; Kahrmanovic et al., 2010; Larson et al., 2012; Roberti et al., 2024; Sugihara & Pinna, 2022) The study examines how the cube, a fundamental geometric form, can effectively convey emotions without relying on anthropomorphic features. It aligns with the growing interest in minimal, non-verbal emotional communication strategies in HRI (Hoffman & Zhao, 2020; Vigni et al., 2022).

The reviewed literature highlights the growing importance of emotional expressiveness in social robotics, extending beyond humanoid appearances to more abstract forms. However, current research remains limited in understanding how motion alone can communicate emotions in non-humanoid robots. This study addresses this gap by exploring the expressive potential of geometric form movements, contributing to the broader goal of developing emotionally resonant yet visually minimal robotic designs.

### **III. Methodology**

This study employs an exploratory mixed-methods approach that involved 30 undergraduate students in presenter and observer teams, aiming to enhance collective reasoning and data gathering through discussions in innovative contexts.

The study employed a wooden cube for manual manipulation in a controlled design studio, focusing on motion-based expression. Participants were randomly assigned to represent one of Paul Ekman's (1992) six basic emotions.

Each presenter team was assigned an emotion and asked to design a movement pattern using the cube. The observer teams then watched each presentation and identified the assigned emotion. Teams were allowed a brief planning phase to discuss their approach. No verbal cues or facial expressions were permitted during the performance.

Participants completed a questionnaire assessing emotional expression using a cube, capturing both quantitative and qualitative responses. The data were analysed using a two-tiered coding process, revealing patterns, themes, and associations between emotions and movement types.

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**Figure 1**

A group of participants engaging in the study

Source: Author



#### **IV. Analysis and Findings**

Quantitative data reveal that the majority of participants accurately identified happiness, anger, and sadness. At the same time, fear, disgust, and surprise received mixed responses, suggesting that some emotions are more effectively communicated through basic movement.

Thematic analysis of participant responses revealed common movement patterns used to express emotions, including rhythm, speed, direction, and repetition.

- Anger was expressed through sharp, fast, and repetitive movements with sudden slams.
- Sadness was expressed through slow, downward, and minimal movements.
- Happiness involved bouncy or circular movements with rhythms.
- Surprise involved sudden, abrupt approaching movements with forwardness.
- Disgust was expressed with sudden turn-back movements.
- Fear was expressed through hesitant, sudden backwards, and trembling movements.

Observers always used tempo, rhythm, and movement direction to determine emotions.

- Neutral or positive emotions, such as happiness and surprise, are related to flowing, smooth movements.
- Negative high-arousal emotions, such as sadness and fear, are associated with rapid movements.

Movement direction, speed, and repetition were frequently used as cues by observers. Furthermore, some participants reported difficulties conveying feelings such as fear or disgust, as they struggled to find a clear way to express them using a cube.

Based on questionnaire data, the majority of the participants were confident about their ability to express the assigned emotion. The expressed emotions had the following mean clarity scores (out of 5): 4.2 for happiness, 3.9 for sadness, 4.1 for anger, 3.1 for fear, 3.4 for surprise, and 2.9 for disgust. Furthermore, based on this pattern, it suggests that negative complex emotions were more difficult to explain and convey than positive or high-energy emotions.

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The cube shape restriction encouraged creative thinking, clear explanations, and improved understanding of emotions through group conversations and logical reasoning.

Many participants mentioned that the lack of facial or bodily elements made the task challenging and interesting. Several observers reported relying on personal interpretation when identifying emotions, indicating that perception was subjective and depended on the context in which it was observed.

The findings show that happiness, anger, and sadness were more accurately recognised, while fear and disgust were often misinterpreted, highlighting the difficulty of expressing complex emotions through geometric forms. Participants primarily used rhythm, speed, direction, and repetition, while observers relied on these cues, incorporating subjective interpretations. The findings of this study align with prior research on motion semantics (Law et al., 2021; Hoffman & Ju, 2014), reinforcing the role of movement features in conveying emotional intent in non-humanoid robots.

Based on these identified patterns, an emotional movement representation was created, providing a foundation for studying how abstract geometric movements can support emotional expression in HRI contexts.

**Table 1**  
*Emotion-Specific Movement Characteristics Identified for Geometric Robot Forms*

<b>Emotion</b>	<b>Movement Quality</b>	<b>Direction</b>	<b>Speed</b>	<b>Rhythm / Pattern</b>	<b>Intensity / Force</b>	<b>Key Features</b>
<b>Surprise</b>	Sudden, fast, unexpected	Backward, away, upward	High, very fast	Irregular, abrupt stop-hold	Medium-High	Upward jumps with sudden hold; Circular spins; Rapid direction shifts
<b>Disgust</b>	Sharp, rejecting, dismissive	Backward, sideways, turn	High, very fast	Repetitive push/turn motions	High, rejecting force	Sudden turn-backs; Slides or tilts away; Half-circle avoidance turns
<b>Fear</b>	Trembling, unstable, defensive	Backward, pulling away	Fast, uneven	No rhythm, shivering pattern	Medium, unstable	Quick backwards pulls; Small, rapid shakes; Jerky trembling
<b>Anger</b>	Sharp, forceful, aggressive	Outward, attacking, away	High, rapid	Repetitive slamming/jerks	Very High, explosive	Sudden jerks, slams; Hard non-rhythmic shakes; Strong pushes
<b>Happiness</b>	Light, flowing, rhythmic	Forward, approaching, open	Slow-Medium	Rhythmic, smooth, bouncing	Medium, gentle	Up-down lifts; Flowing calm gestures; Circular motions; Smooth repetition
<b>Sadness</b>	Heavy, slow, drooping	Downward, inward, retreating	Slow	Continuous, dragging, low energy	Low, weak	Slumped or sinking motions; Downward curves; Slow retreats; Gentle sways; Minimal lift

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## Discussion

The use of movements in a simple cubic form to represent basic emotions was investigated during the conducted study. The findings show that while some human emotions can be expressed clearly, others are more challenging to understand or articulate.

The study found that emotions like happiness, anger, and sadness are easier to express and identify due to their recognisable movement patterns, corroborating findings from previous research. At the same time, fear, disgust, and surprise are often misinterpreted and require more detailed motion or expressive elements to convey their meaning effectively.

Accordingly, motion characteristics such as direction, rhythm, and speed significantly impact how emotions are perceived. Individuals understand abstract motion using internalised representations. The neutrality of the cube drew attention to movement, although it was challenging to do so without conveying voice or facial expressions, highlighting the limitations of form-only communication.

The study reveals that a cubic form can effectively communicate basic emotions, while it possesses limitations. Future research should include other geometric forms and complex movement possibilities, and consider personal background and perception styles to enhance clarity.

These findings have practical implications for the design of non-humanoid robots across various applications. By demonstrating that simple geometric forms can convey emotions through motion, designers can create robots that effectively communicate affect in contexts such as education, therapeutic interventions, or interactive interfaces, even without anthropomorphic features. This approach supports more versatile and emotionally engaging robotic interactions while maintaining abstract or minimalistic aesthetics.

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