The ERROR-MM Project: Exploring Robotlike Robot Behaviours in Users' Mental Models

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Abstract

Design aims to align the user's mental model with the actual behaviour of a device to reduce the gap between user expectations and observed behaviour. In robotics, because of the anthropomorphic attributions that humans make towards robotic machines, humanlikeness has been one of the main heuristics to guide the design of robots, regarding their embodiment as well as their behaviours. Although humanlike design has many proven advantages, it also comes with disadvantages, such as being potentially deceitful regarding the robot's true capabilities. Recently, a new paradigm of robomorphism has been proposed that speculates on the attribution of robotlikeness to things. The ERROR-MM project will explore this novel idea of robotlikeness and test its effect on the accuracy of human mental models of robots. Specifically, starting with movement, as it is the basis of any robotic behaviour, the project aims to test the hypothesis that a robot employing robotlike behaviours will lead humans to form better mental models of a robot's true capabilities than a robot that employs humanlike behaviours.

CCS Concepts

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

Keywords

Social Robotics, Human-Computer Interaction, Robot Behaviour, Robomorphism

1 Introduction

The anthropomorphism towards machines has been strongly inspiring a humanlike design heuristic for robot design [37]. However, this approach is not without drawbacks, including overtrust, mismatched expectations, and ethical concerns surrounding deception. By recognizing these limitations, the ERROR-MM project seeks to pioneer an alternative design heuristic: robomorphic design or robotlike form. It is inspired by the robomorphism paradigm [11] as it emphasizes the robots' nature and inherent features.

The central premise of robomorphism is that humans are increasingly familiar with robots and have begun to associate certain features with the concept of a robot [11]. These associations provide an opportunity to develop a fundamentally different perspective for robot design that leverages robotlikeness as a core principle rather than defaulting to anthropomorphic or humanlikeness. By embracing the distinct, nonhuman nature of robots, robomorphism offers the potential to enhance transparency, reduce deception, and foster more accurate mental models of robots' capabilities.

Building on this premise, the overarching ambition of this research project, entitled Exploring Robotlike Robot Behaviours in Users' Mental Models (ERROR-MM) is to explore the viability and impact of robotlikeness as a design heuristic for robots. Specifically, the project aims to test the hypothesis that robotlike movement leads to better alignment between human expectations and a robot's actual capabilities than anthropomorphic movement, which may create expectations that exceed the robot's actual capabilities.

To achieve this goal, the ERROR-MM project faces one crucial challenge: the limited understanding of what is robotlikeness and how to effectively manipulate robotlikeness and how this concept varies when attributed to robots. For instance, we lack clarity on how to design robots that are consistently perceived as displaying higher or lower levels of robotlikeness. Some researchers have described and implemented robotlike features as the opposite of humanlikeness [2, 12, 16, 41]. This dichotomy is related to dehumanization theories [24], which suggest that the attribution of mechanistic features to humans can strip them of their humanity. Nevertheless, the terms "robotlike" and "humanlike" might not be entirely opposite. As robots are artificially created by humans with humancentric approaches, leading them to often have humanlike forms and behaviours, a certain degree of humanlikeness is expected to exist within the notion of robotlikeness (i.e., the terms "robotlike" and "humanlike" might overlap to a certain extent). Additionally, previous research has considered robotlike as the same as mechanistic or machinelike. However, empirical findings suggest a distinction between the characterization of robotlikeness and machinelikeness [38]. As a result, clarifying how to manipulate robotlikeness is an open challenge.

The research project comprises four tasks: 1) Investigate the perception of robotlikeness in robot movement; 2) Validate, through online studies, manipulations of robot movements with high and low levels of perceived robotlikeness; 3) Computationally develop autonomous robotlike behaviours; and 4) Test the central hypothesis through in-person studies.

Overall, the ERROR-MM project introduces a groundbreaking perspective by shifting the focus from anthropomorphic to robomorphic design, by leveraging the robomorphism paradigm and using robotlikeness as a central design heuristic. Unlike traditional approaches that prioritize humanlike traits, this project explores how embracing the distinct, nonhuman features of robots can address the ethical, practical, and perceptual challenges associated with anthropomorphism. This work holds significant potential to rethink one of the main assumptions in the field of social robotics.

2 Related Work

2.1 Advantages of Anthropomorphic Design in Robotics

Anthropomorphising an object is the attribution of humanlike traits to it, which might refer to human qualities, feelings, or intentionalities [14]. Humans anthropomorphize inanimate objects [21], animated shapes [25], animals [29], or even machines [36]. In the field of Social Robotics, anthropomorphism has been a powerful heuristic to explain the social affordances humans give to robots [13, 20, 37]. One of the key psychological mechanisms behind anthropomorphism is effectance motivation, the intrinsic desire to feel competent by understanding, predicting, and effectively influencing one's environment. When people encounter unfamiliar robots, this motivation is activated by the need to predict their actions and reduce uncertainty [14].

As a result, researchers in the Social Robotics field have been working towards the development of humanlike robots, reflected in the persistent adoption of humanoid shapes [18, 27, 35], and the advancement of autonomous behaviours that are more interactive [19] and socially intelligent [5].

Anthropomorphism has also been acknowledged as an important attribute of robots, with proven positive effects on performance and relational aspects, agency [27], goal achievement [48], and trust [33, 39]. It is also an integral component of commonly used questionnaires designed to assess social robots [3, 6, 40]. Additionally, researchers have shown that certain features, such as embodiment [7, 31], intentional gestures and nonverbal cues [15, 17, 26], group membership [28], or motion features [34, 45], can manipulate the perceived humanlikeness and anthropomorphic attributions towards robots.

2.2 Disadvantages of Anthropomorphic Design in Robotics

Empirical evidence has shown that anthropomorphic designs are not always beneficial. It may introduce a distracting effect in terms of attention allocation [32], mask unethical considerations of robots' selfish behaviours [10], or lead to the "uncanny valley" [30]. Despite its positive effect on user acceptance, trust, and engagement, anthropomorphic design can lead to overtrust and mismatched expectations, and bring the potential for deception and ethical issues [23, 47, 48].

2.3 Novel Paradigms, Concepts & Design Heuristics

A recent analysis of the opportunities and challenges of anthropomorphism has raised a different perspective on the ambivalence of using a mere instrumentalist approach of robots and a mere posthuman approach [9]. Considering this, Coeckelbergh [9] proposes a "third" view on anthropomorphism, which has a critical, relational, and hermeneutic approach and is situated in the middle of current existing perspectives, viewing robots as "instruments-in-relation". Another new paradigm that does not deny anthropomorphism, and goes hand in hand with the "third view" by Coeckelbergh [9], is the robomorphism paradigm [11], which elaborates on the attribution of robotlike traits and features to non-robotic entities. One of the underlying concepts of this novel paradigm is the existence of robotlike (or robomorphic) traits, which are the features found in or associated with robots. This concept assumes that robots can already be viewed with their own characteristics, which embraces their nonhuman nature and is inspired by posthuman theories. Nevertheless, the robomorphism paradigm has its roots in a specific posthuman school of thought, called more-than-human, which includes the relationship between humans and non-humans[11].

Although the robomorphism paradigm was recently proposed, the term "robotlike" is not new in the literature on social robotics, where it has previously been used as a synonym of "machinelike" or "mechanistic". However, research also suggests that these terms may not fully overlap. Schaefer et al. [38] indicated that levels of robotlikeness significantly differ from mechanicallikeness attributions to robots, suggesting a distinction between the characterization of robots and machines. This finding supports the robomorphism paradigm, as it endorses that robotlikeness is a unique characterization.

Lastly, to overview other existing paradigms and design heuristics for robots, the literature also mentions zoomorphic [22], biomorphic [44], and theomorphic designs [43], to name a few.

3 Research Plan

To outline the ERROR-MM project research plan, we will clarify four important considerations and a priori decisions.

First, robotlikeness could potentially be manipulated through various design elements, such as the morphology or physical embodiment of robots, as well as their behaviours. However, given the duration and exploratory nature of this one-year project, we have chosen to focus on a more targeted and manageable approach. Specifically, we will use minimalist robot embodiments and examine the effects of behavioural manipulations. Within this scope, we will concentrate on manipulating robotlikeness through behaviours, with a particular emphasis on robotic movement. Movement is a fundamental aspect of any robotic behaviour, serving as a universal and accessible means of interaction and communication between robots and humans.

Second, we will prioritize methodological reproducibility throughout all project tasks by adhering to the FAIR principles: Findability, Accessibility, Interoperability, and Reusability. These principles serve as a cornerstone for ensuring that our research processes and outputs can be reliably replicated, validated, and extended by the broader scientific community. To achieve this, all methods, protocols, and procedures will be documented exhaustively, including detailed descriptions of the experimental designs, data collection processes, and analytical approaches. We will share these materials on open-access platforms, such as repositories specifically designed for research data and methodologies (e.g., OSF).

To consider the generalizability aspects, and taking into account both the duration and exploratory nature of the ERROR-MM project, we have decided to investigate robotlikeness behaviours across two distinct robotic embodiments: a stationary robot and a mobile robot. These two robotic embodiments will support two distinct application scenarios in the user studies. The stationary robot will likely represent use cases such as information provision, customer assistance, or social interaction in fixed settings (e.g., reception desks, kiosks, or classrooms). In contrast, the mobile robot will be employed in scenarios requiring mobility, such as delivery tasks, patrolling, or collaborative activities within dynamic environments. This strategic choice is designed to enhance the generalizability of our findings by ensuring that the concept of robotlikeness can be examined within a broader spectrum of robotic forms and functionalities.

Lastly, the ERROR-MM project contributes to addressing some of the well-documented disadvantages associated with anthropomorphic design heuristics in robotics. Among the various known effects, our focus will centre on addressing the issue of deception, particularly regarding the affordances and perceived capabilities of robots. Specifically, the project seeks to reduce the gap between a robot's actual capabilities and how people perceive those capabilities.

3.1 Tasks

The ERROR-MM project comprises four main tasks (Figure 1):

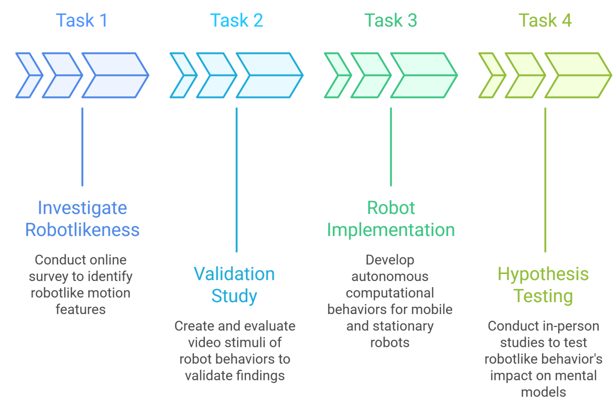

Figure 1: ERROR-MM project workflow

3.1.1 ***Task 1: Explore how to design robotlike movements for robots.*** Our initial task involves conducting a user study to investigate and determine which motion features (e.g., speed, rhythm, fluidity, or patterns) are most effective in manipulating the perceived robotlikeness of robotic behaviours. This foundational step will guide the design of robot behaviours that embody varying levels of robotlike traits in the following tasks of the project. There are two main research questions guiding the first task:
RQ1 - What are the motion features in a robot's movements that contribute to the perception of robotlikeness?
RQ2 - What is the perception of robotlikeness in robot motions?

To collect information enabling us to answer the research questions, we will conduct an online study to gather people's ideas and examples of what constitutes a robotlike motion for robots. The survey will include: (A) a combination of open-ended and closed-ended questions for users to detail a description of robotlike movement and evaluate their own responses; and (B) a mouse-tracking task where participants will draw the robot's trajectory between two points, and mouse positions over time will be collected. The study will manipulate movement type in a between-subjects design with five levels: robotlike as the experimental condition, and human-like movement, animal-like movement, machine-like movement and object-like movement as the four control conditions.

In part (A), participants will be asked to name the five main features of robot movements that lead them to consider their motion as [robot-like/human-like/animal-like/machine-like/object-like]. Then, they will be asked to sort the previously identified features in terms of their importance. Finally, they will be asked to rate the importance of each characteristic with a 7-point likert scale.

In part (B), participants will draw with their mouse the path of a robot movement between two points in two environments, with and without obstacles. In particular, they will be asked to draw the path assuming the robot movement is considered as [robot-like/human-like/animal-like/machine-like/object-like].

Participants will be recruited over the Prolific online platform. An a priori G*Power analysis indicated a minimum required sample size of 200 with an effect size of 0.2 with 80% power at $\alpha = .05$, and assuming a drop-out rate of 20%.

To analyse qualitative results, we will perform a thematic analysis [4] to identify relevant motion features reported by participants. This step will help us clean up and organize the data set by grouping similar features and removing low-frequency responses. We will then use descriptive statistics—means, standard deviations, and distributions to evaluate the importance ratings for each identified feature of the movement. To determine which motion features are perceived as significant for classifying robotlikeness, we will conduct one-sample t-tests. For each feature, the mean importance rating (measured by a 7-point Likert scale) will be compared to the midpoint value of the scale. This will help us assess whether a feature is rated as significantly more important than the average scale value. Only features with mean importance scores significantly above the midpoint will be considered relevant for robotlikeness. To address the second research question, we will examine differences in importance ratings across entity types—such as robot-like, human-like, animal-like, machine-like, and object-like—using ANOVA. In addition, a Chi-square test will evaluate the association between the condition and the most relevant characteristics in each case. Finally, to analyse the quantitative data from the survey's mouse-tracking task, we will extract known motion features from biomechanics literature, including approximate entropy [46] and smoothness [1].

The main result expected from the first task is a description of motion features that influence the perception of robotlikeness, in comparison with perceptions of human-like movement, animal-like movement, machine-like movement and object-like movement.

3.1.2 *Task 2: Validation study of the robotlike behaviours*.
To validate the results collected in Task 1, we will conduct a second user study to evaluate video stimuli showcasing different robot behaviours. Based on the motion features that influence the perception of robotlikeness, humanlikeness, animallikeness, machine-likeness, and objectlikeness, we will create two video stimuli for each motion type in order to manipulate a low and a high level of the corresponding perception, respectively. A total of ten video stimuli will be created and evaluated in a between-subjects online study over the Prolific platform. Each participant will watch one of the videos, randomly assigned, and rate their subjective perception of robotlikeness, humanlikeness, animallikeness, machinelikeness, and objectlikeness with four 7-point Likert-scale questions. We will target a total of 264 participants (determined with a power analysis for ANOVA omnibus test with $df = 7$, $power = 0.8$, $\alpha = 0.05$, $f = 0.25$, and assuming a 10% participation drop-off after attention checking).

We will perform a statistical analysis on quantitative measures to compare differences between conditions and validate that the created video stimuli are perceived as intended.

The main results expected from Task 2 are the validated stimuli and a consequent analysis on the perception of robotlikeness in terms of robotic motion features. Additionally, a detailed discussion on the overlap between the perceptions of robotlikeness and each one of the control motion types (i.e., humanlikeness, animallikeness, machinelikeness, and objectlikeness). Such a discussion will significantly contribute to the understanding of what characterizes robotlikeness, will also shed some light on the intersection between several perceptions and design heuristics, and will ultimately contribute to advance the theoretical paradigm on robomorphism.

3.1.3 *Task 3: Development of scenarios with real robots*.
On the third task, we will translate the validated robot behaviours into autonomous computational implementations for two distinct physical robot embodiments. A mobile robot will simulate typical task-oriented applications, such as delivery tasks, whereas, the stationary robot will simulate a social use case such as serving at a reception desk.

In both scenarios, the robot must execute the task with one of two possible modes: a high level of robotlikeness and a high level of humanlikeness. Both robotlikeness and humanlikeness will be manipulated with autonomous robotic behaviours, using the previously validated motion features (see section 3.1.2).

3.1.4 *Task 4 - Hypothesis testing*.
The goal of the last task of the project is to test the main hypothesis that robots employing robotlike behaviours will enable humans to develop more accurate mental models of the robots' true capabilities, compared to robots using humanlike behaviours.

To test the hypothesis, two empirical studies will be conducted to evaluate the robustness and generalizability of the findings across robot embodiments and application scenarios: a mobile robot in a delivery task and a stationary robot as a reception desk assistant.

The studies will be in-person, each collecting a sample of 128 participants (determined with a power analysis for ANOVA one-way test with $df = 1$, $power = 0.8$, $\alpha = 0.05$, $f = 0.25$). Participants will be assigned to one of two conditions in a between-subjects design: robotlike behaviour or humanlike behaviour. After observing and interacting with the robot, participants will answer a subjective self-assessed questionnaire on their perceptions of the robot's capabilities [8], and perceived fluency as a measure of shared mental models [42].

We will perform a statistical analysis on quantitative measures to compare differences between the two conditions and the hypothesis.

4 Impact

By systematically identifying and characterizing the key motion features that influence "robotlikeness," the ERROR-MM project seeks to ground the emerging paradigm of robomorphism in empirical evidence. Beyond its theoretical contributions, the project establishes a rigorous framework for future HRI research by strictly adhering to FAIR principles, ensuring that these findings are not only reproducible but serve as a robust foundation for exploring the evolving nature of human-robot interaction.

Ultimately, if the core hypothesis is validated, this exploratory project has the potential to redefine the design heuristics in the field of robotics. By demonstrating the advantages of robomorphic design, the project could catalyze a paradigm shift, positioning robotlikeness as a viable and superior alternative to anthropomorphic design. This shift would emphasize transparency, accuracy, and ethical considerations in how robots are designed and perceived, opening new pathways for innovation.

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