

Embodied Trust in Elderly-Care Robots: A Theoretical Shift and Dimensional Construction of User Trust Assessment

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Abstract: Human-robot trust has been extensively researched in virtual interaction environments, leading to a “disembodied” model. However, embodied intelligent robots for elderly care exist in the real space as tangible entities. Their physicality may influence the process of building trust fundamentally. In this study, motion semantics is considered an important analytical approach to explore how the characteristics of a robot’s movements affect the establishment of trust in elderly users. By combining the findings from previous studies on human-robot trust and embodied cognition, the study proposes the concept of “embodied trust” and suggests a causal relationship between movement attributes and perceived predictability, which subsequently impacts the sense of control and safety, thus affecting the development and preservation of trust. Furthermore, the research takes into account two other factors: the effect of movement synchrony on adjusting trust over time and the special sensitivity of elderly people to such movement clues. It is believed that motion semantics plays a crucial role in embodied trust — the mechanical properties of the robot influence the users’ perception of behavioral predictability, which in turn affects their sense of security and control, thereby promoting or impeding trust building and maintenance. From the practical viewpoint, the study put forward three strategies for motion interaction design in embodied elderly-care robots: maintain natural and predictable movements, keep movement consistency, and adopt a gradual increase in movement speed.

Keywords: Embodied intelligence; Elderly-care robots; Motion semantics; User trust; Age-friendly design

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1. Introduction

1.1. Research background

China is facing a rapidly increasing elderly population. In 2024, the population over 60 years old has increased to 310 million, which constitutes 22.0% of the national population ^[1]. Due to the shortage of elder care facilities, intelligent robots have become an attractive supplement to traditional care services. They are

now being used in home-based care environments, moving beyond laboratory conditions.

What distinguishes embodied AI from conventional digital systems is its capability to work in the real world. Embodied elderly-care robots, not only as screen devices but as actual objects, enter the private living areas of the elderly. The authors believe that their actual existence modifies the relationship between humans and robots fundamentally. Nevertheless, the main difficulty for their application is not insufficient technical progress; it lies in the lack of users' trust.

Several scholars have pointed out this issue. Li and Jiang mention that the current embodiment of intelligent technology encounters several difficulties in the field of elderly care, including the lack of sufficient technical maturity, unresolved safety problems, and unclear ethical limits ^[1]. Wang et al. present empirical findings indicating that the willingness to use home-care robots is influenced by three interrelated factors: their functional performance, the perceived emotional support, and the quality of interaction ^[2]. Han and Ye also emphasize that without proper regulatory measures, the implementation of intelligent care systems will be affected by a “trust barrier” at its base ^[3]. In summary, these accounts indicate that the user's trust has become an important obstacle preventing the extensive use of embodied elderly-care robots.

1.2. Problem statement

Most of the current methods for assessing the trust between humans and robots have been established in situations involving screen-based interactions. They mainly base trust on the rational evaluation of the system's performance and predictability made by the users. This method functions reasonably well for desktop programs, but its applicability decreases when the interactive entity is no longer a “system behind a screen,” but a robot that occupies the same physical space as the user.

Campagna and Rehm have also pointed out that the conventional method of questionnaires is liable to post-hoc rationalization and thus cannot fully reflect the change of trust through time ^[4]. However, this criticism, though significant, does not solve the basic problem. The majority of the human-robot trust evaluation schemes treat “non-physical systems” as the referent object, ignoring the effect of physical embodiment on the conditions under which trust is established.

The idea of embodied intelligence involves its physical features. These robots occupy space and have mass and volume. They can move independently and come into direct contact with objects. Urakami and Seaborn indicated that non-verbal signals, such as spatial arrangements and motion semantics, are significant for robots to seem “alive” and to establish trust ^[5]. Nevertheless, these traits are not taken into account in the present “disembodied” trust system.

Among various forms of interactive communication, motion semantics should be paid more attention. It is the direct clue that people recognize most quickly and uniformly during an interaction — every action, every turn, and every change in speed transmit the intention, reliability, and controllability of the robot. This leads to the main problem discussed in this paper: how do the movement characteristics of robots influence trust building in elderly users? The study takes this issue as the starting point to explain embodied trust.

1.3. Research purpose and significance

This paper aims to promote the “embodied turn” in the study of human-robot trust. The study starts with motion semantics, considering the movement features of robots as sources of information related to trust and examining how these features affect the process of trust establishment in elderly users. The main theoretical contribution the authors intend to prove is a causal relationship between movement features and the

perception of predictability, which in turn influences trust.

What is its importance? According to the theoretical perspective, integrating motion semantics into the research on age-friendly trust might lead to a more effective solution than the present “unsatisfactory” model. The authors think that the movement features are beneficial and contain some types of information. The manner in which a robot moves indicates certain properties and possible actions. Moreover, the system the authors have designed is intended to assist in the construction of age-friendly motion interactions and offer suggestions for the planning of movement routes, control of speed, and organization of the robot’s behavior.

This investigation also involves a more general issue. Li and Wang have pointed out a “care gap” between the care provided by robots and that provided by humans, in the four aspects of attention, responsibility, ability, and responsiveness^[6]. The motion-semantic aspect, which the authors emphasize, can now be considered a theoretical reply to this gap — an effort to define one part of the care to which robots should pay attention in order to be accepted by their elderly users.

2. Theoretical foundations: From “disembodied trust” to “embodied trust”

2.1. The “disembodied” tradition in human-robot trust research

Research on the relationship of trust between humans and robots is based on the interpersonal trust theory. The comprehensive model put forward by Mayer and his colleagues defines trust as “the readiness of a party to be in a disadvantaged situation towards the behavior of another party, expecting that the other will take an advantageous step beneficial to the trustor”^[7]. This definition has been applied and modified in the investigation of human-robot interaction. For instance, Lee and See regarded human-automation trust as “the confidence that an agent will support the achievement of an individual’s goals under unpredictable and risky circumstances”^[8]. Hancock et al. have also studied human-robot interaction and presented a definition with stress on dependency and welfare: “the reliance of an agent on important others who do not harm its welfare”^[9].

One may also doubt whether the definitions used in human-human or human-automation situations can be applied easily to human-robot interaction. The problem becomes more serious when the robot is not a screen-based system but a physical agent which occupies the user’s space. The current research on human-robot trust, based on the period when most interactions were through screens, considers trust mainly as a result of cognitive evaluation — users judge the reliability and predictability of the system and then make a decision on whether to trust it. This view is suitable for desktop applications. However, it is not clear that this applies when the interacting party changes from “a system behind a screen” to “a robot in physical space.”

Hancock et al. have already indicated this in their meta-analysis, although implicitly^[9]. They classify the antecedents of trust into three categories: human-related, robot-related, and environmental, and demonstrate that the robot-related factors are the strongest predictors of trust. However, their classification is still at the level of categorical description. They have not explored deeper: does the presence of the robot affect the basic principle of trust formation? The authors believe that this question has not been sufficiently discussed yet.

2.2. Insights from embodied cognition theory

Embodied cognition theory provides a suitable interpretation. The main idea is that cognition is not only related to the brain, but is also influenced by the structure of the body, its sense and movement abilities, as well as its continuous interaction with the surroundings. For the human-robot association, this viewpoint indicates that trust is not simply a cognitive judgment of a device. It also develops and changes by means of physical contact.

Recently, some researchers have investigated this idea and put forward interaction frameworks which include a perception–interpretation–response sequence. They indicated that even virtual agents could gain trust by means of appropriate embodied feedback. A significant research direction is from Webb and his colleagues, who studied the influence of the co-movement between humans and robots on the development of trust ^[10]. Their results are impressive: the degree of movement synchronization is closely related to the changes in reported trust. When the humans and robots move together, trust increases; conversely, if the synchronization disappears, trust decreases.

These results have a significant effect on the study of older people. The decline in physical ability with age, changes in sensory perception, and increased attention to the surrounding space make the physical aspect of interaction particularly important for this group. Cognitive functions slow down. It becomes harder to adapt to unforeseen situations. Under such circumstances, the ease, predictability, and control of physical interaction are not only concerns about usability, but also relate to the psychological safety and, consequently, to the establishment and maintenance of trust.

2.3. Core differences between “disembodied trust” and “embodied trust”

The contrast that has been considered needs to be clarified further. According to the discussion mentioned earlier, the authors suggest distinguishing between two types of trust — one “disembodied” and the other “embodied.” The main differences are presented in **Table 1**.

Table 1. Core differences between disembodied trust and embodied trust

Dimension	Disembodied Trust	Embodied Trust
Interaction object	System behind a screen	Physical entity in space
Basis of trust	Cognitive evaluation (reliability, predictability)	Sensory-bodily experience (safety, control)
Information channels	Visual + auditory (language/interface)	Visual + auditory + tactile + spatial perception
Trust formation	Rational judgment	Integration of bodily perception and cognitive evaluation
Specificity for older adults	Low	High (physical decline, spatial sensitivity)

What is then embodied trust? The study gives an initial working definition: embodied trust denotes the trust condition produced by the perception-action cycles between the users and the physical agents—this condition is based on what the users feel and experience during the interaction, not only on what they think about the agent.

This statement is based on the meta-analytic results of Hancock and his colleagues ^[9]. They pointed out that the presence of the robot, regardless of its location relative to the user, affects trust and obedience. In comparison with a virtual existence, a physical robot can enhance the possibility of people’s trust and obedience towards its instructions. Though their conclusions are not expressed in this way, they illustrate the difference the study has mentioned: embodied trust is not only a type of non-embodied trust. It acts via multiple pathways and reacts to different clues.

Motion semantics is the main method for users to gain the most direct and uninterrupted feeling in an interaction. The authors will focus on this point now.

3. Theoretical construction of the motion semantics dimension

3.1. Conceptual definition of motion semantics

The authors call the non-verbal messages expressed by robots through their motion properties as motion semantics. Such as smooth trajectories, consistent changes of velocity, preparatory turning actions, and

accelerating-decelerating patterns, these are the features of a robot's movement style. They form a type of "body language," similar to the posture, gesture, and walk that humans use to express social information. Motion semantics do not contain explicit semantic meanings as language does. However, it significantly affects one's perception of a robot's intentions, emotional condition, and reliability.

Scales and his collaborators have done a comprehensive investigation on this issue ^[11]. They have performed several perception experiments both online and in person to examine the effect of different motion patterns on social-emotional attribution. The results indicate that robots with smooth and continuous movements are usually considered "confident" and "reliable." On the other hand, robots with sudden and saccadic movements are perceived as "insecure" or "unreliable." This indicates that the motion features are not only important by themselves but also convey information concerning trust. It is clear that the way a robot moves is not of minor significance compared to its actions; rather, it has a considerable influence on its actions.

3.2. Movement characteristics → Predictability perception → Trust: The core theoretical pathway

Trust mainly relies on the stability of actions. If people can foresee the behaviors of a robot, they will have better control. Otherwise, they will feel uncomfortable. Scales and his colleagues have shown this relationship. In their research, they discovered that movement features like smoothness and coherence of the route, especially, affect the trust evaluations ^[11]. The robots that have "human-like" movements, for example, preparatory movements before turning, smooth deceleration patterns, and natural acceleration-deceleration cycles, are thought to be more comprehensible and intentional. They seem reasonable instead of random or unpredictable. This stability of prediction is important for enhancing the feeling of control. And this feeling of control can increase trust.

The reverse is also true. If the movements are too violent, rapid, or abrupt, an alarm will be activated. The users will be more careful, less satisfied with operating the robot, and regard it as unreliable or unsafe.

Expressing differently, the recommended logical connection is a definite cause-effect relationship: motion semantics → the feeling of predictability → the sense of control → trust. The kinematic properties of the robots, like continuity, stability, and previous actions, affect the users' capability to foresee the robots' behaviors. This impression will influence the users' sense of control and safety. In the end, these mental states decide the formation and preservation of trust. It must be taken into consideration that these movement features are applied not only for executing tasks. They also convey information to the users, showing the robots' characteristics, their future actions, and their reliability.

3.3. Movement synchrony: The dynamic calibration mechanism of trust

A complementary angle is based on the study of Webb and his colleagues ^[10]. They performed field experiments to explore another related topic: the influence of the degree of synchronization between humans and robots on real-time trust. According to their results, an increase in trust occurs when the movements are synchronized. Conversely, trust decreases when the synchronization fails, i.e., when the robot's timing is inaccurate, or its actions differ from the user's.

Two points should be mentioned. Firstly, trust is not a constant state; it changes with the degree of synchrony at every moment. This indicates that the process of trust calibration is continuous and dynamic, rather than a single evaluation. Secondly, proximity in space is important. The synchrony only indicates trust within a particular range — according to the study by Webb et al., about two meters. Beyond this distance, the influence becomes weaker.

According to the results, the impact of motion semantics on trust is not the same in all cases. It is influenced by the situation. If two people are near each other, the properties of their movements, such as smoothness, time, and coordination with the observer, affect the variation of trust. But when the distance is greater, these movement attributes may not be correctly detected by the observer.

3.4. The particular sensitivity of older adults

If the motion semantics are important in general for trust, they are even more significant for older people. This has been demonstrated in a study by Chen, who interviewed 407 Chinese adults over 50 years old^[12]. The results are worthy of attention: the perceptions of the robot's appearance and movement features have a significant influence on the negative attitude towards the robot ($\beta = 0.316, p = 0.024$). It indicates that for older users, the movement design is not only concerned with the establishment of trust, but also with the possibility of destroying the established trust instantly.

Why do the elderly show a greater sensitivity towards these hints? Two reasons are proposed. Firstly, their cognitive functions decrease with age, and they find it hard to adjust to unforeseen circumstances. Secondly, changes in their sensory organs and physical conditions cause them to focus more on the spatial and temporal features of the interaction. Therefore, a robot acting in a “rigid” or “fast” manner is not only ineffective but also frightening. A minor unexpected movement might result in a lack of trust between the user and the robot.

This does not imply that all the elderly are completely unwilling to get help from robots. Instead, it suggests that more conditions need to be fulfilled to gain their trust. Experiments on robot systems for the elderly confirm this opinion: the robot's performance reliability is important in deciding whether the users accept its advice and correct its errors. If the robot's behavior is steady and continuous, it indicates safety and capability. On the contrary, if its behavior is unstable, it will have the opposite effect, which can be easily observed.

Mistakes should be eliminated instead of enhancing the efficiency of motion interaction in elder-care robots. A continuous and uniform movement is not a supplementary characteristic; it is necessary for establishing and maintaining trust.

The proposed theoretical model is illustrated in **Figure 1**.

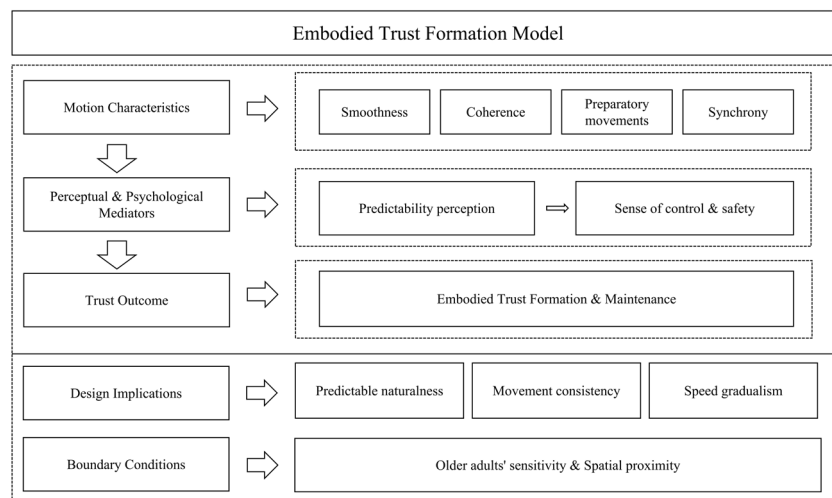


Figure 1. Theoretical mechanism model of embodied trust formation and its design implications

4. Discussion: Theoretical significance and design implications

4.1. Theoretical significance

This paper presents three contributions, each related to a particular level of the analysis system the authors have constructed.

The first point is about the concept of embodied trust. By emphasizing the role of motion semantics as an important research aspect, the authors aim to indicate that trust in human-robot interaction cannot be well described by frameworks that regard the robot as a “system behind a screen.” The existing methods, such as Mayer et al., Lee and See, or Hancock et al., generally consider disembodied systems as their reference ^[7-9]. The authors’ viewpoint brings the body back into consideration. Consequently, it brings to light a fact that has been overlooked by the earlier frameworks: the movement characteristics are not only irrelevant to trust; they carry trust-related information themselves.

The second contribution is theoretical. By combining the findings of Scales et al. concerning motion profiles and Webb et al. about movement synchrony, the authors have developed a pathway model which indicates how movement characteristics affect trust: characteristics → predictability perception → trust ^[10-11]. Unlike the existing classification of trust antecedents, the model explains a causal process. It not only considers the categorical influence of robot-related factors but also investigates the detailed influence of these factors.

The third contribution is about the features of old age. Chen et al. did not interpret the negative attitudes toward the physicality of robots from the perspective of motion semantics ^[12]. The model explains the significance of physical attributes from the perspective of the elderly: motion semantics operates through bodily sensations, and bodily sensations become more evident and easily stimulated when physical ability declines. The elderly are not only more cautious; the authors think they are more responsive to the clues that motion semantics perceives. Hence, the design of friendly motion interaction for the aged should not be an extra enhancement but a necessary requirement for trustworthy robotic care.

4.2. Age-friendly motion interaction design strategies

Thus, what do these aspects imply in practice? The framework puts forward three related design elements for age-friendly motion interaction.

The first kind is called predictable naturalness. The main principle is simple: the control of movement should regard predictability and smoothness as two equally significant goals, not as alternatives. In actuality, this requires including human-like kinematic features such as preparatory small movements before turning, smooth acceleration and deceleration curves, and avoiding sudden changes in speed, while keeping the same behavior in different similar operations. A robot displaying these characteristics seems easy to understand. One can predict its next action. And this feeling of prediction, especially for an elderly person, is directly related to a sense of security.

The second important point is the preservation of movement continuity. It refers to the result obtained by Webb and his associates that coordination is associated with confidence ^[10]. During every building process, the regular rhythm of movement should be kept, and if a change in the movement pattern is unavoidable, the robot should show it by decreasing its speed, making a short stop, or giving a clear signal of changing direction. In this situation, constancy does not mean stiffness. It indicates providing a trustworthy foundation for the subjects to form their expectations, so any difference can be recognized and regarded as important rather than surprising.

The third important matter is to adopt a gradual method to adapt to the reduced cognitive speed and difficulty in adapting that often happen in old age. For instance, starting and stopping should be done gradually. A preparatory stage should be before performing the action of turning. When approaching a person, the robot should follow a varying speed sequence: faster at a longer distance, then slower at a medium distance, and finally moving slowly when near. The aim is to give time for the person to comprehend the situation, to make changes, and to feel that the robot does not dominate but is polite.

These three points should be used at the same time. They are not separate schemes to be carried out individually, but parts of a complete action. When used together, the robot appears to be easily predictable and manageable for the old people — not from the viewpoint of logical thinking, but from their physical sensation. The authors think that only in this manner can satisfaction finally be gained.

4.3. Research limitations and future directions

It is necessary to point out what this paper has not accomplished. The objective is to propose a conceptual framework and a causal relationship, but the authors have not verified it by experiment. The model presented is a hypothesis rather than a proof. This is a disadvantage, but the authors hope it will attract others' attention.

The authors' subsequent research may be conducted in various fields. One of the main tasks is to establish uniform evaluation methods for motion semantic perception, such as scales or behavioral indicators, which can reflect how individuals interpret and react to different types of movements. Otherwise, it will be hard to carry out empirical tests on the pathway model.

A further investigation should be to carry out controlled experiments on the proposed pathway. The movement features such as smoothness, coherence, and preparatory movements could be changed separately to examine their influences on trust, and to verify if the perception of predictability and sense of control play a mediating role as the authors have suggested.

A third aspect deals with spatial context. The study on synchrony indicates that the trust of motion semantics might be affected by distance. The hypothesis that the effect decreases beyond a certain range can be verified by adjusting the proximity in experimental conditions.

Furthermore, this model is applicable to various subgroups of elderly individuals. Aging is a complicated process. Individuals with different physical, sensory, or cognitive capabilities may have varying responses to movement hints, and a better understanding of these differences will enable us to provide more suitable suggestions for the designs.

These are not chance ideas. They indicate, in some sense, the subsequent reasonable steps according to the framework. The authors intend that by clarifying the model, the authors have also rendered it testable, and that others will continue this research.

5. Conclusion

This document has tried to accomplish three objectives: identifying a problem, suggesting a concept, and establishing a route.

The problem the study mentioned is that the present human-robot trust models, mainly relying on screen communication, are based on a “non-physical” principle. They regard trust as a mental assessment, which is a rational judgment on the credibility and predictability of the system. This may be applicable to clarify the relationship between the users and the system displayed on the screen. But it is not adequate when the system

turns into a physical object that can be moved, take up space, and share the user's environment. The authors think that the integration of physical existence not only affects the trust condition, but also changes its basic principles.

The proposal the authors suggest to deal with this issue is embodied trust. It refers to a trust condition arising from the interaction between the users and the nearby agents, not only based on mental judgment but also affected by physical feeling. Moreover, the method is related to the meanings of the movements. The authors think that the kinematic features like smoothness, uniformity, and preparatory actions influence the users' judgment on the regularity of the behavior; this judgment affects their feeling of control and safety; and these psychological states decide the establishment and maintenance of the trust relationship. What the authors intend to explain is that the movement properties are advantageous not only for the execution of the task, but also for transmitting some information. They indicate what the robot is, what it is going to do, and whether it can be trusted.

Research shows that elderly persons are more responsive to such signals. The reduction in their cognitive processing speed and adaptability results in greater mistrust due to minor movement errors. Hence, the motion interaction design for the elderly should not be regarded as an additional advantage, but as an essential requirement for the use of robotic devices in elderly care.

Furthermore, what is the significance of this framework? The authors think it lies in incorporating the body into the study of human-robot trust. Hancock et al. noticed the importance of physical presence for trust and cooperation previously ^[9]. However, the authors believe this observation has not been sufficiently explained theoretically. The motion-semantic framework which the authors have established aims to meet this requirement — to define the processes by which physical presence works and to express the implications of these processes on the design.

Empirical research is necessary to verify the pathway the study has suggested. Controlled experiments can investigate the mediating role of the perception of predictability and sense of control on the effect of various movement features, and whether these effects differ among older people. However, the authors believe that by clarifying the model, by defining its variables and the proposed relationships, the authors have made it feasible to test it. Actually, this is the aim of a theoretical framework: not to solve the problem, but to make it suitable for further study.

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Disclosure statement

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