The Usage and Evaluation of Anthropomorphic Form in Robot Design

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Abstract

There are numerous examples illustrating the application of human shape in everyday products. Usage of anthropomorphic form has long been a basic design strategy, particularly in the design of intelligent service robots. As such, it is desirable to use anthropomorphic form not only in aesthetic design but also in interaction design. Proceeding from how anthropomorphism in various domains has taken effect on human perception, we assumed that anthropomorphic form used in appearance and interaction design of robots enriches the explanation of its function and creates familiarity with robots. From many cases we have found, misused anthropomorphic form lead to user disappointment or negative impressions on the robot. In order to effectively use anthropomorphic form, it is necessary to measure the similarity of an artifact to the human form (humanness), and then evaluate whether the usage of anthropomorphic form fits the artifact. The goal of this study is to propose a general evaluation framework of anthropomorphic form for robot design. We suggest three major steps for framing the evaluation: 'measuring anthropomorphic form in appearance', 'measuring anthropomorphic form in Human-Robot Interaction', and 'evaluation of accordance of two former measurements'. This evaluation process will endow a robot an amount of humanness in their appearance equivalent to an amount of humanness in interaction ability, and then ultimately facilitate user satisfaction.

Keywords

Anthropomorphic Form; Anthropomorphism; Human-Robot Interaction; Humanness; Robot Design

Humans have effectively used robots to perform physical labor and replace human workers in performing tasks in dangerous, hazardous, and unhygienic places. Recently, various types of robots have become commonplace. In addition to replacing humans in factories, robots are being used interactively with humans in homes, offices, and public spaces. Once domestic robots progress from a manual labor and begin moving around our physical and social spaces, their roles and our dealings with them will change significantly. To adapt robots to new environments, industrial designers have applied anthropomorphic form to robots. Anthropomorphic form provide users with clues about the product's function, mode-of-use, and qualities, as well as a perception of what the product says about its owner or user, that is, the personal and social significance attached to the design. Giving an anthropomorphic form to the shape and motion of a robot helps humans perceive the robot as an artifact that actually lives with them and shares the same space everyday. Adaptation of robots to our environment contributes to building social relationships between humans and robots, and the appeal of robots can be enhanced based on strong social relationships.

Robotics engineers and researchers have placed enormous attention on addressing the question of how to endow robots with human-like intelligence. However, robotic artificial intelligence has not effectively been achieved, and has not reached human intelligence level. Followers of weak artificial intelligence believe that the contradictory term "artificial intelligence" implies that human intelligence can only be simulated. They argue that the most common way an artificial system can become "intelligent" is when it cheats humans. The robot is yet told to be cheating to appear intelligent. There is thus debate over whether robots will ever be as intelligent as some have imagined. Even if we ignore the controversial argument of followers of weak AI, there is a certain limit to AI that can currently be implemented in robots.

Nevertheless, there are various ways to compensate for current technological limitations and enhance a "perceptive" robot's intelligence. The design of robots plays an important role in helping humans to perceive robots as smart. Design can control the degree of perceivable humanness of an artifact. Yet designers have paid relatively little attention to the importance of adjusting the degree of humanness of robots in their design. Every technology passes through an immature phase in which human models are used as metaphors for design. Lewis Mumford describes this process in the chapter, "The obstacle of animism" in Technics and Civilization (1934): "…the most ineffective kind of machine is the realistic mechanical imitation of a man or another animal". Misused anthropomorphic form for robot design may raise the problem that users misconceive robots as a perfect servant or secretary that can perfectly support them.

This study examines the problems of discordance between the use of an anthropomorphic form in the appearance and level of intelligence of a robot. The core of this study is proposing an evaluation of the design of robots by measuring the degree of humanness in their anthropomorphic form.

Anthropomorphism

"There is a universal tendency among mankind to conceive all beings like themselves… We find human faces in the moon, armies in the clouds." – David Hume, The Natural History of Religion (1757).

Anthropomorphism has been noted for centuries throughout human thought, yet to many it remains inexplicable. By nature anthropomorphism cannot be eliminated; it occurs as one result of a perceptual strategy that is both involuntary and necessary. Though literature is one of the representative areas where anthropomorphism is employed, there are also arguments against it use in writing. Once philosophers revealed the intentions underlying its use, it became a less attractive rhetorical device. Numerous philosophers, natural scientists, and others have long criticized the practice of anthropomorphism. Despite this scrutiny, a thorough account of the causes of anthropomorphism has yet to be presented. Instead, two explanations – that it comforts us and that it explains the unfamiliar by the familiar – have, singly or together, been widely assumed (Roboert W. Mitchell, Nicholas S. Thompson, & H. Lyn Miles, 1997). While the application of anthropomorphism in the area of design area is also motivated by these goals, it is neither a dominant design method nor a target of strong criticism.

Anthropomorphism in the Design Field

Anthropomorphism is defined in Webster's New Collegiate Dictionary (1977) as the "attribution of human characteristics to nonhuman things or events". In terms of design, anthropomorphism can be applied to the form of an artifact. Form is not limited to static features such as shape and color. Form can also be related to dynamic features such as movement. Therefore, it is necessary to find anthropomorphic forms for products, not only in terms of how they look, but from an entire set of experiences users acquire when they interact with products. To observe how the design of products delivers experiences to users, it is necessary to first generalize the qualities of form, and then study the underlying qualities of anthropomorphic forms in cognitive and social contexts of their use. This paper begins by posing two areas where designers can apply anthropomorphic forms to industrial products, appearance and interaction.

From the viewpoint of a semantic approach, "experience", our objective for measurement, stands for complex, contextualized "meaning" under considerably various circumstances. Objects are always seen in a context (of other things, situations, and users, including the observing self)(Ulrich Neisser, 1976). Objects such as products that perform multi-function tasks generate more complex meaning in accordance with contextual changes. What a thing or product represents (the totality of its meaning) to someone corresponds to not only actual contexts but also to its imaginable contexts. The context into which people place the object they see is cognitively constructed, whether recognized, anticipated, or wholly imaginary. A future domestic service robot is expected to have a great diversity of uses; a 'service robot' will not typically have a single prominent use. Vacuuming, carrying a newspaper, turning off the television, and chatting with the user examples of functions that are imaginable to ordinary people. In contrast with the case of a robot that can perform only a single task among those, people refer to different robots from their own experiences with robots and assume the robot can perform multiple tasks, and they accordingly respond to the robot with imaginable contexts. Therefore, observing variable meanings for variable contexts is practically impossible. We therefore decided to simply observe meanings that can be objectified largely according to the designer's efforts. In other words, we decided to control the context of the product's use. Therefore, we narrowed "meaning" to "form" as our objective to measure, thereby circumventing the problem of dealing with uncontrollable contexts.

Klaus Krippendorff (1984) outlined four essentially different contexts in which objects may take on meaning in different ways.

- *operational context*, in which people are seen as interacting with artifacts in use
- *sociolinguistic context,* in which people are seen as communicating with each other about particular artifacts, their uses and users, and

thereby co-constructing realities of which objects become constitutive parts

- *context of genesis,* in which designers, producers, distributors, users, and others are seen as participating in creating and consuming artifacts and as differentially contributing to the technical organization of culture and material entropy

- *ecological context,* in which populations of artifacts are seen as interacting with one another and contributing to the autopoiesis (self-production) of technology and culture

Among Krippendorff's four types of contexts, form is explored only in an operational context in this study. Efforts of designers to control the humanness level of products by applying anthropomorphism initially affect meaning in an operational context. Other meanings that diverge from the initial meaning then follow in other contexts. If we attempt to study respondents' reactions in other contexts (e.g. a sociolinguistic context), observations will have to be carried out for a considerably long period of time. Also, when respondents are more familiar with the given objects, they will perceive the object wholly differently. Thus, it is apparent that we cannot purely observe people's reaction toward an object in terms of its design itself if we conduct long term observations.

Classification of Anthropomorphizable Domain

Carl DiSalvo, Francine Gemperl, & Jodi Forlizzi (2005) addressed the question of classifying anthropomorphic form from the designer's point of view. DiSalvo et al. classified anthropomorphic form into four groups, structural anthropomorphic form, gestural anthropomorphic form, anthropomorphic form of character, and aware anthropomorphic form. The distinctions between the four groups were derived from examining evidence of anthropomorphic form in designed artifacts. However, rather than classification of anthropomorphic form, we focus on classifying the domain to which anthropomorphism is applied, because we deal with anthropomorphic forms as the targets of observation and evaluation in this study.

In light of the background presented above, we break down the anthropomorphizable domain into two areas, 'appearance' and 'interaction'. Most design efforts for precedential robots are conventionally related to appearance. The design of interaction between human and product is considered to fall within the realm of the industrial designer's responsibilities. When developing an intelligent product such as a robotic product that has perceptive, cognitive, and action ability, the appearance of a product must be designed with consideration of its interaction style, and vice versa, because most interactions when a robot is processing perception, cognition, and action are expressed through physical features of the robot, i.e.,"features of appearance"

Fig 1. Classification of anthropomorphizable domain

Appearance and interaction are intricately related. Initially, we planned to test pure interaction in developing our evaluation method. We realized early on that this is impossible, however, because the two are indivisible in the perception of the user/respondent. There is no movement devoid of form. Anthropomorphism cannot be sharply divided into these two categories. In particular, a robot's movement is a core means of communication in human-robot interaction. However, there are few references to provide an initial clue for how to test pure appearance or interaction. For instance, from experiments, Robert Young, Daniel Pezzutti, Stuart Pill, & Richard Sharp (2005) claimed that when people react with products where movement occurs at low speeds, they notice qualities of appearance more, whereas at fast speeds the message/information is determined more from the movement than the appearance.

Usage of Anthropomorphism: Appearance

There is a long history of designers imitating human form. Artifacts that have anthropomorphic form can be found everywhere in our daily lives. The usage of anthropomorphic form in design was manifested mostly in the appearance of artifacts in the past. This history goes back thousands of years to ritual vessels (Carl DiSalvo, et al, 2005). At that time, the makers of these artifacts attempted to use human form straightforwardly. The shapes of vessels have a strong association with the human body. This bald expression of human shape makes an explicit statement about the purpose of anthropomorphism at that time. Although the use of human appearance for vessels was required for religious reasons, anthropomorphism was not always intentionally employed. Form in appearance may be recognized as an anthropomorphized form not only when it is originally designed as such but also when it is merely interpreted in this way.

Humanlike forms can be found in contemporary design as well. The front of an automobile can be thought of as resembling a human face. People commonly compare headlamps or tail lamps of an automobile with human eyes. The image of the automobile evokes the characteristics of humans. Since eyes are one of the most significant visual features among all facial features with respect to forming facial expressions, automobile designers pay deliberate attention to the design of headlamps and tail lamps, which are interrelated with the overall characteristics of an automobile. People may associate the shape of lights with friendly or angry eyes of a human face. This association has a major impact on the impression the viewer has of the appearance of automobiles.

Observing anthropomorphic form in products requires not only interpretation of the designer's intention but also people's cognitive response to the products. When reviewing the work of Crozier(1994), Cupchik(1999), Lewalski(1988), Baxter(1995) and Norman(2004), a strong precedent emerges for using the following three categories to describe cognitive response to product appearance: aesthetic impression, semantic interpretation, and symbolic association(Nathan Crilly, James Moultrie & P. John Clarkson, 2004). Aesthetic impression is defined as the sensation that results from the perception of attractiveness (or unattractiveness) in products. Semantic interpretation is defined as what a product is seen to say about its function, mode-of-use, and qualities. Symbolic association is defined as the perception of what a product says about its owner or user: the personal and social significance attached to the design. These three cognitive responses can be found in every artifact. However, the influence of each response on the whole cognitive response may differ according to the attributes of an artifact. Also, the influence of anthropomorphism on each response may differ according to the attributes of an artifact. In the case of a ritual vessel, anthropomorphic form serves as a linchpin connecting symbolic association. The humanlike body shape of the vessel recalls its implications for sacrificial rituals.

Anthropomorphic form in products has increasingly been used for functional purposes rather than symbolic and religious purposes. The appearance of an object can create an affordance that provides the user with perceivable possibilities for actions. James. J. Gibson (1979) claimed, 'The object offers what it does because it is what it is''. Hence, this term can be interpreted as meaning that appearance is one of the most significant elements of an artifact in terms of explaining its functions and capabilities. Designers need to understand visual cues that indicate required operations or intended functions of a product. As functions of a product become more complex, designers increasingly rely on affordances to encourage a semantic interpretation.

Biomimetic Form / Anthropomorphic Form

Affordances originate from different types of metaphorical sources, for example, a plant, an animal, or a human. Several research teams have been developing new types of industrial products with new, improved functional qualities using biological and bionic analogies. Biological forms, coloring, structures, constructions, functionality, and general aesthetic appearances found in the natural world (botanical as well as zoological organisms or parts of them) serve as models for promising applications in creating useful designs.

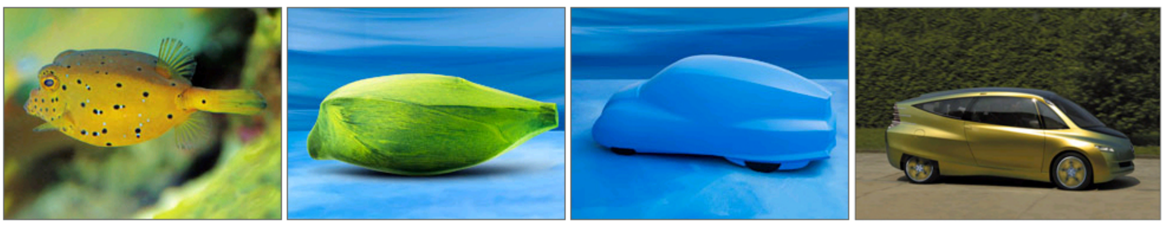

Fig 2. Example of biomimetic form (Mercedes-Benz bionic car, 2005)

As an example, engineers, designers, and biologists at Mercedes-Benz worked together to develop the Mercedes-Benz bionic car (2005). Its template was a sea dweller from tropical latitudes: Ostracion Cubicus – more commonly known as the boxfish. Despite its unusual-looking shape, the fish is extremely aerodynamic and can therefore move using a minimal amount of energy. It is also able to withstand high pressures and, thanks to an outer skin consisting of hexagonal bone plates, can survive unscathed following collisions with corals or other sea dwellers. These characteristics are also ideal for a car designed to achieve the best possible levels of energy efficiency and passenger safety. This is known as "biomimetic design". Biomimetic design enhances a product's technical performances as well as facilitating semantic interpretation.

For robots, various types of metaphors have been used for their design. This started with organisms such as insects or animals that can be imitated relatively easily. As developed technologies began trying to imitate complex human features, anthropomorphism emerged as an important issue in both robot engineering and design. Merriam-Webster online dictionary describes a robot as a "machine that looks like a human being and performs various complex acts (as walking or talking) of a human being". As defined here, the basis of a robot comes from human beings. If the robot is a humanoid type robot, all of its component should be designed with consideration of the human body.

Usage of Anthropomorphism: Interaction

Anthropomorphism has also been effectively used in the design of interactions between humans and products. Anthropomorphism in interaction can be delivered through a multimodal interface. Appearance can be delivered only through visual languages, but interaction can be manifested through auditory, tactile, and other languages. For example, sounds made when a car door is opened and shut can be associated with different human characteristics. A low-pitched sound supports the assignment of a dignified and noble human character to a car. Although the car door sound is not a human voice, it is interpreted as a human feature in this case.

Concern for gender differences and the adaptation of a human emotion model in the development of human-robot interactions are other examples of the usage of anthropomorphic form in interaction design.

For robot design, anthropomorphism is a persistent problem, because we must refer to our human experience in order to formulate questions about experience we derive in human-robot interaction. As robots come nearer to our everyday life, interaction between robots and human occurs with increasing frequency.

Usage of Anthropomorphism: Relationship between Appearance and Interaction

One of the early Japanese roboticists, Masahiro Mori (1970), proposed that as robots become more humanlike, they become, to a degree, more familiar. However, as with a human corpse, they risk becoming eerie when they appear too human, especially when they are discovered to be mechanical through touch or by other means. If design concerns are not carefully managed for robots, anthropomorphic forms used in the design of their appearance can have a detrimental influence on human perception and preference.

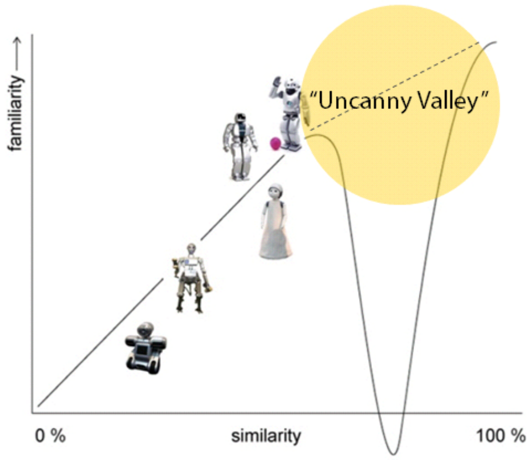

Fig 3. Masahiro Mori's 'Uncanny Valley'

The term 'Uncanny Valley' refers to a graph of emotional reaction against the similarity of a robot to human appearance and movement (fig 3). The term was coined by Mori, although it is often wrongly associated with his later work "The Buddha in the Robot" (1982). As a machine acquires greater similarity to humans, it becomes more emotionally appealing to the observer. However, when it becomes disconcertingly close to a human there is a very strong drop in believability and comfort, before finally achieving full humanity and eliciting positive reactions once more; this is the Uncanny Valley. However, if robots have an amount of humanness in their appearance equivalent to an amount of humanness in interaction ability (intelligence), this drop, i.e., the "uncanny valley", can be avoided.

Fig 4. Ever-one (KITECH, 2006) & Robokin-M01 (Sejong Robotics, 2006)

Ever-one/two of Korea Institute of Industrial Technology (KITECH) and Robokin-M01/F01 of Sejong Robotics (fig 4) are highly analogous to living models in appearance. The major application of these types of robots is communication with humans, which is accomplished using a certain level of facial expressions and speeches. However, the perceivable humanness of the robots' intelligence cannot yet satisfy its uncommon similarity of appearance. Thus far, these robots have remained in the laboratories as experimental platforms for further research and development. Before these robots can be implemented to serve humans as intelligent products in the home or office, designers should consider the problem of discordance between anthropomorphized level appearance and interaction ability. Such discrepancy can lead to user disappointment or negative impressions.

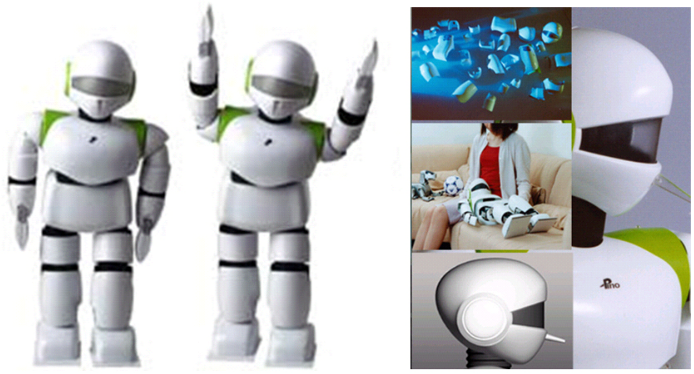

Fig 5. PINO (Tatsuya Matsui, 2000)

An attempt to harmonize anthropomorphism of appearance and interaction is shown in fig 5. By comparison with human's walking, PINO's technical capability of walking was no better than that of a one-year old child. Matsui then tried to control the robot's humanness level of appearance at its limited humanness level of movement. Design metaphors for PINO were the fictional character Pinocchio (original character made by Carlo Collodi, 1883) and, at the same time, a toddler. Body shape and proportion are identical with a one-year old child who has just learned to toddle. People tend to have unrealistically high expectations regarding futuristic and imaginary artifacts, which may be represented by robots. This attempt by Matsui helped to reduce people's false expectations on this biped robot's performance.

Measuring Cognitive Response to Anthropomorphism

When people are asked to verbally report on nonhuman things, they often employ adjectives that describe human characteristics. This helps explain the strong relationship between verbal cues from their expressions and perception to the anthropomorphized objects. Regardless of whether the object is originally designed in an anthropomorphized form or it is only perceived as such, human characteristics are attributed to it. Accordingly, verbal reporting on anthropomorphic form is applicable evidence to evaluate anthropomorphism. When developing criteria to measure the usage of anthropomorphic form, it is necessary to collect verbal adjectives that directly illustrate the human features related to the form. The criteria known as the Big Five as well as those denoted by the acronym MBTI are useful tools for this.

These adjectives and criteria must be reorganized in accordance with the purpose of anthropomorphism. For instance, when measuring the usage of anthropomorphic form of a teaching assistant robot, adjectives illustrating the well-known quality of educators were collected and reorganized using a factor analysis. After measuring the humanness of a robot in terms of both appearance and interaction using appropriate criteria, it was necessary to check whether one value parallels the other. Synthetically, we propose that there are basically three steps (fig 6) to evaluate the usage of anthropomorphic form: designing measurement criteria, measuring humanness in both appearance and interaction, and evaluating the degree of symmetry in the two values.

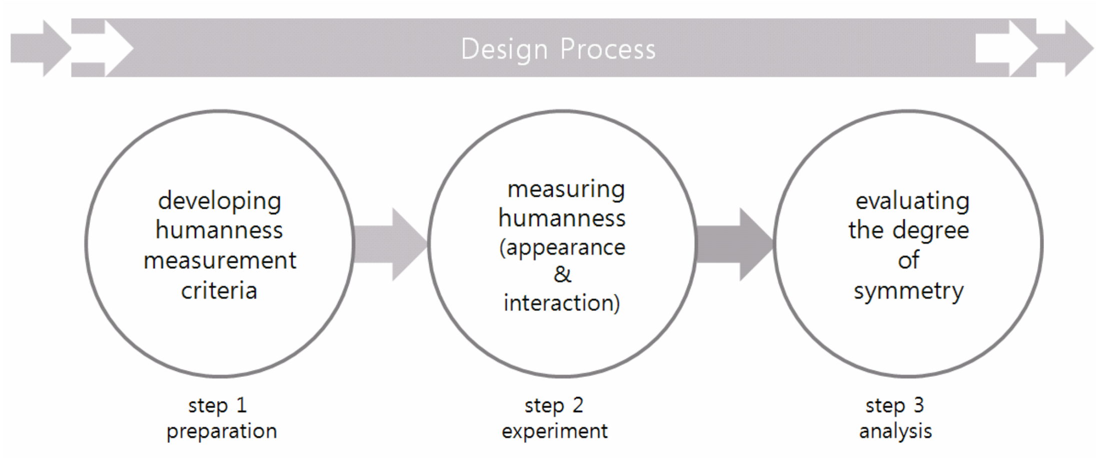

Fig 6. Evaluating steps of the usage of anthropomorphic form in design process

Exemplification of Evaluation: Measuring Humanness

Experiments of measuring humanness were only for incorporating our proposed evaluation steps in concrete level. It was an initial trial for conducting each step in the evaluation. Aim of experiments was not finding a design solution from data we obtained, but elucidating the relationship between humanness of a robot and participants' preference for the robot.

Measuring robots' appearance: The pictures of existing robots were made into cards, and these were used in the robot image evaluation experiment for children. The names of the robot and other explanations were excluded, as it was felt that children may be influenced by other information in addition to the appearance of the robots. Participants performed the image mapping with 43 pictures of existing robots, and sorted the robots according to its humanness, similarity of an artifact to the human form (fig 7). Taking 24 children that were fourth grade schoolers in Daejeon were selected as participants.

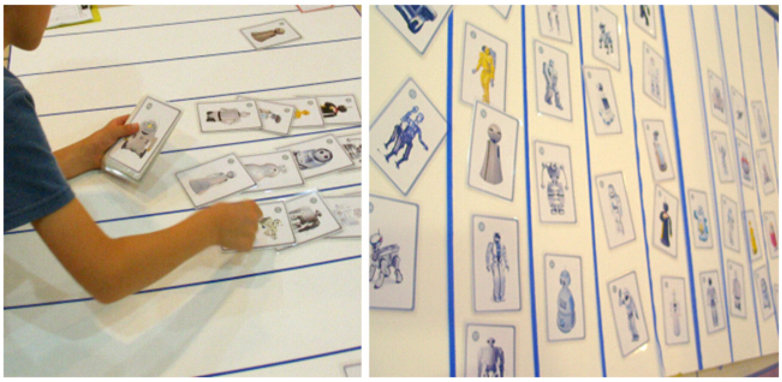

Fig 7. Evaluating existing robots' appearance

Measuring robot's interaction : Measuring humanness robot's interaction abilities requires different criteria for different role and performance of robots. Therefore, we developed criteria for evaluating a teaching assistant robot's humanness in interaction between the robot and children as a sample case. The criteria were composed of verbal adjectives representing a teacher's typical characteristics and well-known qualities. The qualities of teaching-assistant robots can be established by reconstructing the qualities of human teachers, who perform a similar role to that of the teaching-assistant robots. The qualities of teachers are usually the concern of the field of pedagogy. 113 people comprised of teachers and student teachers participated in this questionnaire (web-based). With the data of this questionnaire, the qualities were grouped by factor analysis, for the case of teachers and teaching-assistant robots. As a result of the factor analysis, primary 24 qualities grouped into 6 factors, and these 6 factors (Table 1) were used for evaluation criteria.

Table 1. Humanness measurement criteria for teaching assistant robot's interaction

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
	Tenderness · Kindness	**Leadership**	**Knowledgeabilit y**	**Flexibility**	**Reliability · Patience**	**Sincerity · Impartiality**
	Tenderness Kindness	Leadership	Accuracy Agility	Flexibility	Reliability	Sincerity Impartiality
Role images	Clemency Dignity Sense of duty Paragon Educational affection	Competency	Knowledgeability		Patience	

For measuring humanness in robot's interaction, we used a five-lane board (scored 1 to 5), so the closer the robot was to a similar image for the given criteria(role image factors), the more often the card was placed to the right end, that being the higher scoring end. Same participants with measurement of appearance performed the image mapping with movie clips of 6 representative robot's (out of 43 robots) interaction with users.

Discussion

To design any types of robot appearance and interaction, it needs to find proper level of humanness which fits to its primary task and role. We are not able to demonstrate specifically what level is proper for a teaching assistant robot from the limited result of our experiments. However, we figured out that humanness in interaction ability of teaching assistant robot is fixed at a certain level for its given role and task, and the suitable level need to be answered in design stage (humanness measuring step). Only then, we can find a appropriate humanness level of appearance according to its humanness level in interaction.

The most significant message which our evaluation framework delivers is making designers aware of accordance of humanness level in appearance and interaction in their designing stage. From the exemplification we conducted, we could verify the assumption that humanness of appearance and interaction should be in accordance.

During the execution of the case study, a few more implications for designing evaluation criteria were found. Measuring the absolute value of the humanness of the anthropomorphic form used in robots may not be possible. Participants always required comparative samples when they rated the humanness of robots. Participants understood the term 'humanlike' as 'natural' or 'realistic', because they assumed that robots were inevitably human-based. When showing movie clips to allow participants to see how robots interact with users, blocking the part of the robot that was not related to the present interaction proved to be a critical issue. The results of the experiment strongly supported the hypothesis that disparity between the humanness of robot appearance and interaction promotes a negative influence on preference toward robots.

Conclusion

When people describe anthropomorphic forms of robots, they frequently use the words "natural" or "realistic" instead of "humanlike". One of the critical questions in robotics is how to develop a robot that perfectly mimics human features. This bears testimony that anthropomorphism is a fundamental robot design metaphor. On the other hand, anthropomorphism is not imperative. Employing humanlike forms or interactions is not always an appropriate choice for all kinds of robots. Even for humanoid type robots, perfectly mimicked form or interaction is not the best answer to attract and satisfy users.

Although many people assume that robots will eventually become just like humans and they will serve their users in the same manner as human servants in the home, this is not likely to be realized for some time to come. People tend to have greater expectations for robots compared to what robots can actually do considering the level of current technology. If people become disappointed due to the gap between their expectations and reality, they will be apt to consider robots not as friends but merely as machines. To narrow this gap in perception, designers must achieve harmony between the appearance of the robot and its interactions when using anthropomorphic forms.

We did not attempt to develop an "evaluation method of anthropomorphism" to inform other designers of how they should do better robots, but rather we provide a starting point for criticizing and reflecting on seemingly 'natural' ways of designing robots.

Acknowledgements

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