Motion Design for Nonverbal Communication with a Humanoid Robot

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Abstract

In the near future, humanoid robots will act as the partners of human beings in daily life. Among numerous human-like competencies, motion of humanoid robots is critical for providing humans with richer interactions with such robots. Motion plays an essential role in complementing spoken communication. Moreover, the motions of humanoid robots generate nonverbal communication in various contexts. Through this nonverbal communication, humans can interact with robots not only directly but also indirectly or even unconsciously, as if the robot were simply part of the environment.

Before the developments of humanoid robots, embodied conversational agents (ECAs) were introduced as virtual embodied representations of humans that communicated multi-modally with humans and there has been a great deal of research on ECA behavior. ECAs and humanoid robots share many features in terms of how they communicate with humans. Nevertheless, simply adapting knowledge gathered from current ECA studies to a humanoid robot study is insufficient for the following reasons: 1. ECA studies lack knowledge focused on nonverbal communication, which has become more important in the physical world; 2. ECA studies have focused on developing agent-centered intelligence rather than a user-centered experience; 3. ECA studies have developed logics to generate motions automatically rather than to provide designers with the practical knowledge necessary to design desirable motions.

Motivated by these three arguments, we seek to pioneer a new field of motion design between robot engineering and design discipline. To bring this motion study into design discipline, we focused on human-centered experience through nonverbal communication with a humanoid robot. This paper aims to outline sharable user experience in order to help designer create desirable motions for humanoid robots in various speechless contexts.

Keywords

motion design; nonverbal communication; humanoid robot; sharable user experience

Recently, personal computers, digital gadgets and even home appliances are being designed to speak to the user. Product designers consider more anthropomorphic approaches in order to design our daily goods in an intuitive and interesting way, which is closely related to the trend of robotizing. The boundary between robots and products is blurring. Still, robots are superior to other products in one area: motion. The movable body parts of robots can provide higher pleasure beyond usability or intuitiveness. The humanoid body may be the best strategy to resonate human experience. There have been plenty of gesture studies on virtual characters, or embodied conversational agent (ECAs), however, not many of these studies have attempted to infuse ‘soul’ into such entities in terms of user-centered experience. Therefore, it is necessary to establish such design knowledge to support designers who wish to create desirable experiences that users will want to have, enjoy and share. The following chapter will identify the trends and limitations of previous studies on motion-based interaction with humanoids in order to verify the necessity of a user-centered perspective in motion design.

Review of related work

ECAs can be regarded as the ancestors of humanoid robots, as they have similar body features for human-like communication. Research on ECA behavior has influenced the behavior of robots. The most typical approach focuses on the relationship between verbal language and behavior. Cassel et al. (2001), for example, developed the 'BEAT: Behavior Expression Animation Toolkit' system to generate ECA behavior by extracting linguistic structures of text. For more natural synthesis of motions, Kipp et al. (2007) analyzed a number of gestures from human actors and applied them to the ECA. It is basically possible to transfer the behavioral algorithms from ECA research to humanoid robots. Kushida et al. (2005) tested the knowledge-link between those two lines of research and noted the additional benefits of a physical humanoid robot. Kidd and Breazeal (2004) explained the superiority of a physical robot in terms of providing better absorption, interest, credibility and dependency than ECAs.

Despite all of these connections between ECAs and humanoid robots, simply adapting knowledge from current ECA studies to a humanoid robot study is insufficient. First, ECA studies deal with the virtual world, not the physical world. Second, ECA studies have a tendency to develop agent-centered intelligence rather than a human-centered experience. Third, ECA studies have developed logics to generate motions rather than to provide designers with practical knowledge to design desirable motions. Regarding the first argument, some of the studies mentioned above have tested the possibility of knowledge-transfer from ECAs to physical robots; others have tried to emphasize the superiority of real-world-based interaction compared to virtual interaction. However, those benefits of the physical robot cannot be achieved unless we consider that physical robots share space in humans' daily lives. Humanoid robots cannot be hidden even when they have to remain 'nonverbal' for a large period of time. Therefore, nonverbal communication should be properly managed in terms of motion design to avoid damaging the entire human-robot interaction (HRI) experience. With regard to the second argument, developed algorithms and markup languages have dealt with generating automatic behaviors according to ECA speech. Many of these approaches have focused on developing the communicability of the ECA in an artificial intelligence (A.I.) sense. However, we also need to approach the quality of the experience from a user-centered perspective. Considering the third argument, previous studies have developed the better algorithms that cause an agent to perform motions for proper interactions with humans. Many of these studies created systematic logics by conducting literature studies, taking observations, performing experiments or even capturing humans' motions. Nevertheless, their final outputs, markup languages or the agents themselves seem to be complicated for direct use by the motion designers. We anticipate that the user-centered approach could provide designery insights to overcome all three of these limitations.

Nonverbal communication *gestalt* through humanoid motion

As reviewed in the section on related work, nonverbal communication is also critical for the overall HRI experience, and thus practical knowledge for the design of humanoid motion needs to be established. This chapter provides a baseline from which to apply the user-centered perspective to nonverbal communication with humanoid robots.

Human body and nonverbal communication

Relative to verbal communication, nonverbal communication has a closer relationship to the human body. Every language transfers messages on a certain level. Humans have developed verbal language as a social protocol for clearer and more effective communication. On the other hand, within our daily lives there is a higher proportion of time in which we remain nonverbal. Though we can stop speaking, we cannot stop communicating because the body is always in motion (Goffman, 1963).

Nonverbal communication generally means ‘nonverbal and non-vocal communication’ in which the mouth is not used to generate linguistic words or sounds. Semiotics for nonverbal communication assumes that the human body can function as the *signifiant,* the medium of communication, and studies how the human body performs symbolic functions or may even unconsciously influence other humans (Poyatos, 1976). Gestures, body language, kinetics, signals, gaze, tactile communication and proxemics are related to nonverbal communication (Kim et al., 1998).

Successful communication requires a consensus between both parties of the communication. According to Argyle (1975), nonverbal communication can easily be one-sided; nevertheless, as Goffman observed, we never stop communicating because our bodies never stop moving. Considering the intention of the sender, the perception of the receiver and the influence on the receiver, there can be 6 patterns of nonverbal communication, as shown in Table 1.

	Intention of sender	Perception of receiver	Influence on the receiver
1	O	O	O
2	O	X	X
3	O	X	O
4	X	O	O
5	X	X	X
6	X	X	O

Table 1 Patterns of nonverbal communication

The first case is the most ideal nonverbal communication, in which the sender and receiver share intended and perceived meanings. On the other hand, the second and fifth cases are not truly communication, because communication assumes interaction. However, the third and sixth cases are different from the first, second and fifth cases. Although the receiver does not fully understand the sender, the motion of the sender influences the receiver, regardless of the sender’s intention. In brief, nonverbal communication may occur at various levels of concentration and communicator interaction. Nonverbal human motion may sometimes communicate only a small piece of information, such as ‘I am alive,’ or may even communicate nothing at all. Some motion can be reinterpreted from the receiver’s perspective. In that sense, nonverbal communication is similar to art, which communicates sharable messages where reinterpretation according to the different experiences of the audience is partly expected.

Nonverbal communication Gestalt

Motion design for a humanoid robot is different from teaching motions to a human. Designers have to design all motion details for the robot, because even unconscious motions, which express the minimum lifelikeness, are not intrinsic behaviors for robots. To design such motions for a humanoid robot, we need to understand the concept of interaction gestalt. As Lim et al. (2007) explained, “interaction takes on a *gestalt,* a composition of qualities that creates a unified concept, configuration or pattern which is greater than the sum of its parts.” In the same sense, Moore (1922) stated, “not simply the whole, but its constituent parts could not survive that destruction of other parts.” In such an organic whole the constituent parts have a relation of mutual causal dependence on one another. This study agrees with these ideas of Moore and Lim. First, we separate motion design attributes from the type of nonverbal communication used. However, this approach is not an analytic approach which would issue a formal definition giving art necessary and sufficient conditions or an algorithm for classifying and evaluating its works. Dewey (1934, p. 155) said that such "formal definitions leave us cold." Therefore, we argue that a set of motion design attributes, the elements of interaction, can be projected as a unified gestalt, by projecting them into a type of nonverbal communication. This study intends to concretely identify the relationship between motion design attributes and nonverbal communication in order to outline sharable experiences to design desirable motions for humanoid robots. We acknowledge the fact that experience is never the same from one individual to another and unique reinterpretation occurs in each instance of communication. Indeed, it would be advantageous for the motion design activity to be wide-open to a varied audience, similar to the way the arts communicate.

Motion design attributes for humanoid robots

A humanoid robot can be defined by its ability to communicate in a human-like manner, rather than its superficial resemblance to humans. Of course, the communicational ability of a robot determines its appearance, and thus robots have come to have similar morphological elements to humans to some degree. Though there is no clear boundary defining humanoid robots, any robots with the proper body elements and motion ability for human-like communication can be considered as humanoids. Because of their human resemblance, the motion design for humanoid robots needs to be carefully considered so users do not develop detrimentally false expectations of the robot's capabilities (Duffy, 2003).

Dance is gaining in importance as a means of conveying body knowledge: it is perceived as an art form in itself and is becoming the subject of research. Dance study seeks to establish knowledge of how to interpret and produce body motions to sublimate dance as an archive, medium and interface between art and science, which is similar to the purpose of this study. The renowned researcher Rudolf Laban (1988) identified principles of human body movements and systematized the four attributes of movement: weight, time, flux and space. Based on these 4 attributes, we held a workshop to establish sub-attributes. Doctoral students, who had experience in HRI design projects from the industrial design department, participated in the workshop. First, participants brainstormed all of the adjectives that represent motion design attributes for humanoid robots. Next, they watched the 3D animation movie 'Robots (FOX, 2005),' which contains a set of well-refined imaginative ideas about how humanoid robots move, to supplement the initial brainstorming. Then, we printed those adjectives on sticky memos for use in a grouping session. Similar attributes were combined and opposite attributes were paired to become sub-attributes of weight, time, flux and space. Finally, we established eight sub-attributes: speed and scale for weight, rhythm and repetition for time, smoothness and accurateness for flux and direction and proximity for space. See the following for descriptions and Figure 1.

A. Weight: indicates the energy of motion. For a humanoid robot, more energy can mean more information or dominance, which is more easily perceived. Weight is proportional to both the speed and scale of motion.

- ***A-1. Speed (slow-to-quick)***: indicates how quickly the humanoid's body parts move from one point to another. There is a continuous spectrum from slow to quick, which is always a relative concept. However, slow motion is perceptively distinguished from a stopped motion. (Example: Slow beat motion ↔ quick beat motion ↔ trembling motion)
- ***A-2. Scale (small-to-large)***: indicates how wide or long the humanoid's body parts move from one point to another. There is a continuous spectrum from small to

large, which is always a relative concept. But, a small motion is perceptively distinguished from a stopped motion. (Example: timid hurrah ↔ powerful hurrah)

B. Time**:** indicates the degree of regularity or tension during a period of time. For a humanoid robot, this attribute can be related to character and emotions. There are two sub-attributes, rhythm and repetition.

- ***B-1. Rhythm (Static-to-Rhythmic)*****:** indicates the level of cadence. There is a continuous spectrum from static to rhythmic. Static motion seems to be drier and more function-based than rhythmic motion. On the other hand, rhythmic motion can be perceived as more artistic, as in dance. (Example: greeting by simple nodding ↔ greeting in a Hip-hop style)
- ***B-2. Repetition (Non-repetitive vs. Repetitive)*****:** indicates if there is any pattern of motion. Some motions can be performed only one time (non-repetitive), such as tracking something or by direct manipulation from an outside force, while another motion can be repeated as pre-programmed. (Example: continuously facing a moving object vs. rotating the head several times for stretching)

C. Flux**:** indicates the degree of tension in a stream of motion. For humanoid robots, this attribute can determine how lifelike they appear. There are two sub-attributes, smoothness and accuracy.

- ***C-1. Smoothness (Stiff-to-Smooth)*****:** indicates how naturally the trajectory of the motion curves. This is a relative concept within a continuous spectrum from stiff to smooth. In general, static motion is more machine-like and less human-like than smooth motion. (Example: popping dance ↔ waving dance)
- ***C-2. Accuracy (Approximate-to-Accurate)*****:** indicates how precise or sophisticated the motion is. This is a relative concept within a continuous spectrum from approximate to accurate. The need for accurateness depends on the level of information. (Example: directing north ↔ pointing at a specific object)

D. Space**:** indicates the orientation and distance of the motion in a physical space. For the humanoid robot, this attribute can be related to dominance and character. There are two sub-attributes, direction and proximity.

- ***D-1. Direction (Inward-vs-Outward)*****:** indicates the directional characteristic of a motion. It can move inward or outward. In general, inward motion is easily perceived as passive or unconscious while outward motion is perceived as active and coming from a dominant character. (Example: shrinking motion vs. blooming motion)
- ***D-2. Proximity (Far-to-Close (vs-touch))*****:** indicates the distance at which the motion is perceived. This is a relative concept within the continuous spectrum from far to close. However, a close motion is distinguished from a touching motion. A distant motion is more difficult to perceive than a closer motion. A short distance between social entities can mean a closer relationship; therefore a touching motion may be the best approach for that purpose. (Example: waving hands from a long distance ↔ waving hands at a close distance vs. shaking hands)

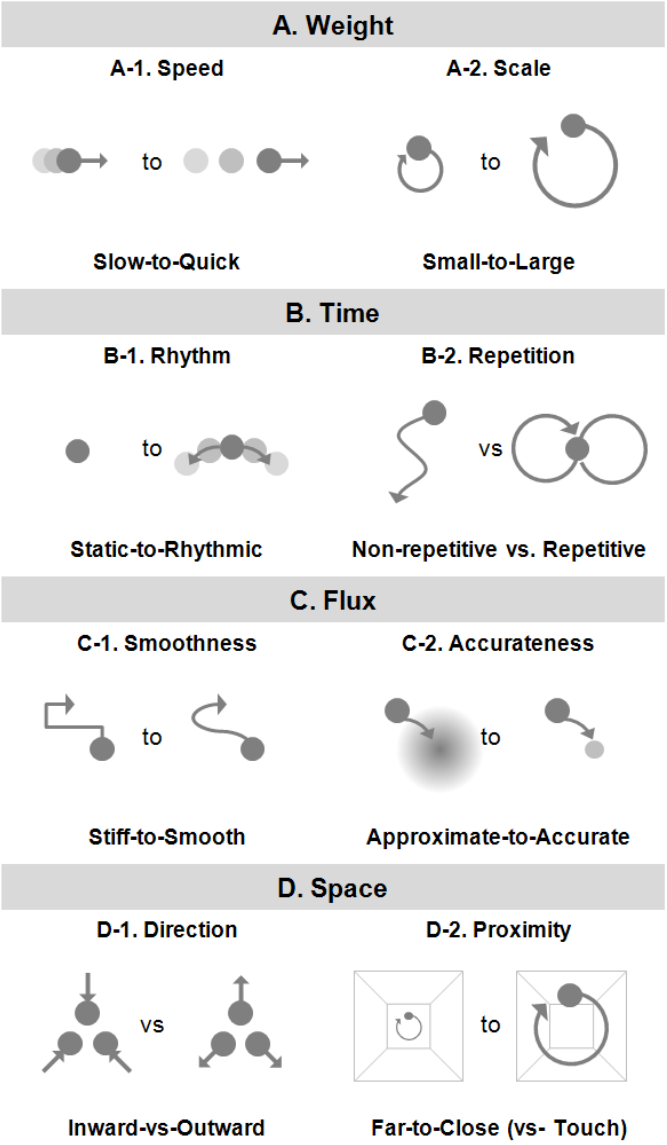


Figure 1 Motion design attributes for the humanoid robot

The established set of motion design attributes are not meant to be deconstructive; rather, we intend to provide them as general set of communication gestalt for humanoid robots. Of course, as these are general attributes, they can be used for other types of robot as well. However, we distinguish the social-oriented characteristics of a humanoid robot within a relationship using the following four types of nonverbal communication.

4 types of Nonverbal Communication Design for the Humanoid Robot

As we saw in Table 1, there are six kinds of nonverbal communication. However, design can deal with only four of them because the second and fifth cases were the result of miscommunication, which is never the designed aim. This chapter explains the four remaining types of nonverbal communication in the context of motion design for a humanoid robot. By considering the intention of the robot and the perception of the human audience, we can imagine the contextual conditions and name the situations as direct, diluted, bridged and ambient nonverbal communication. See the following descriptions and Figure 2 and 3.

1. ***Direct Nonverbal Communication***: This form of communication assumes that both parties of the communication consciously concentrate on one another. Therefore, this is often limited to one-on-one communication. By performing body motions, a humanoid robot can send a message (relatively clearer than the other types of nonverbal communication) to the human audience, which the human tries to understand and respond to, based on what he or she understood. Direct nonverbal communication can be more easily understood within verbal communication. For example, the robot can use symbolic gestures such as sign language, express emotions or even participate in physical contact, such as shaking hands.
2. ***Diluted Nonverbal Communication*:** This form of communication assumes a special situation where a humanoid robot tries to send messages to an audience of multiple humans. Unlike in direct nonverbal communication, the human audience does not have to concentrate on the robot but is unconsciously influenced by its motion. Therefore, the audience is usually distracted and the communication is typically not accompanied by eye contact. For example, the humanoid can make motions intended for advertisement at a shopping mall or a dancing motion for performance on a stage.
3. ***Bridged Nonverbal Communication*:** This form of communication assumes the opposite condition of diluted nonverbal communication. A humanoid robot unconsciously responds to environmental changes or people around it. When the robot performs responsive motions, eye contact or joint attention may occur, which the human audience can possibly perceive as interest or curiosity on the part of the robot (Duncan et al., 1977). Therefore, motion that is designed for bridged nonverbal communication implies a readiness for the next form of communication, so it provides more opportunities to initiate or sustain direct communications with the human audience. For example, a humanoid robot can look around as if searching for something interesting, turn its body toward some sound or nod in response to what humans say to it.
4. ***Ambient Nonverbal Communication*:** This form of communication is the weakest of the four types of communication. Both parties remain unconscious of the communication, but sense their coexistence. The humanoid robot naturally expresses its lifelikeness through motion so that the human unconsciously perceives it as alive. If the robot stops its motion people might consider it as a burden, which can be bothersome. Ambient nonverbal communication is a sort of bridged nonverbal communication that helps people believe they can start to interact with the robot anytime they wish. For example, the robot can perform a breathing motion, a neck stretching motion, a thinking motion or act sleepy.

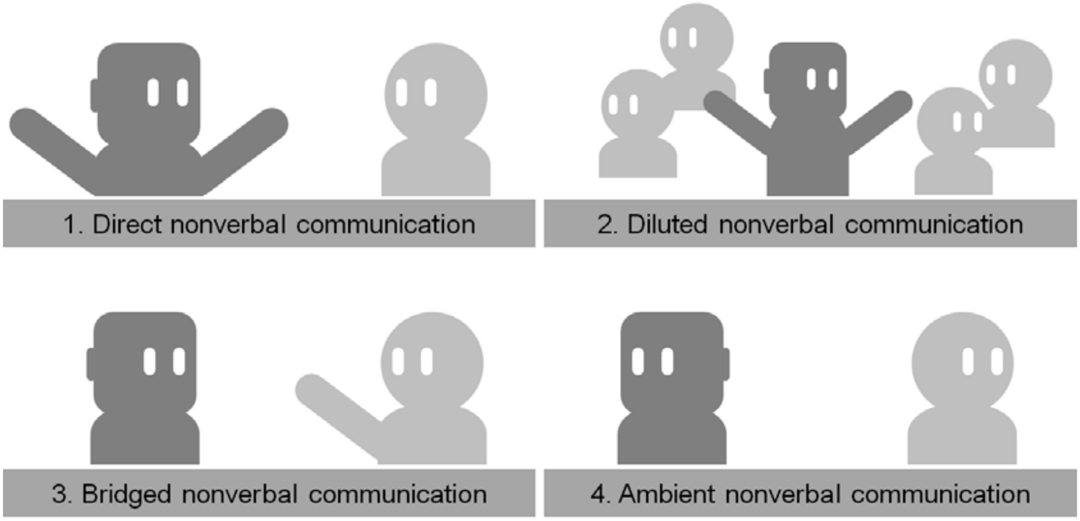


Figure 2 Four types of nonverbal communications with a humanoid robot

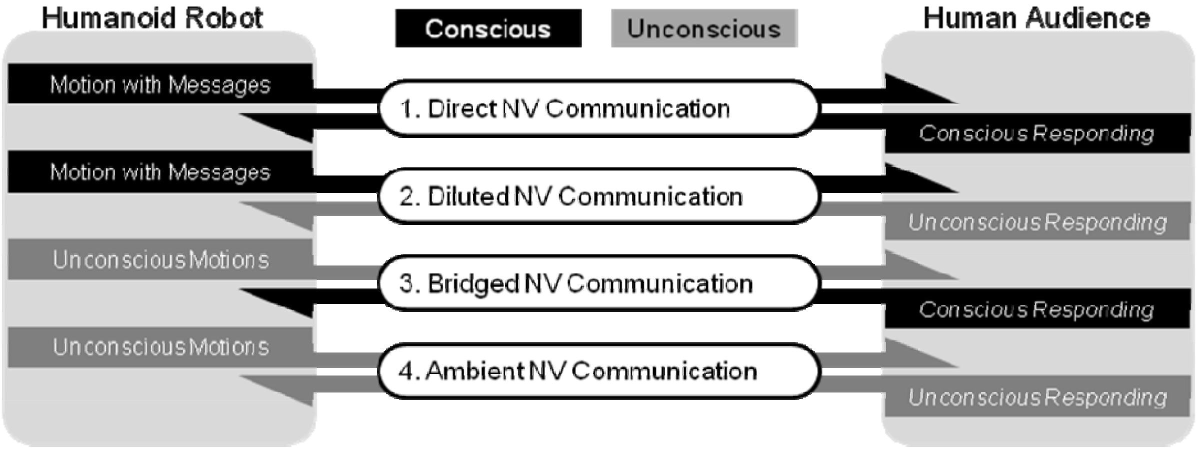


Figure 3 Responding patterns of human audiences for the four types of nonverbal communications with a humanoid robot

Survey to identify sharable user experience

In order to identify the relationship between the motion design attributes and types of nonverbal communication, we conducted a simple survey. The hypothesis was that some of the motion design attributes have significant tendencies in relation to a specific type of nonverbal communication. For example, most people might agree that the speed for ambient nonverbal communication needs to be slow. This is not for judging the validity of motion design, but for outlining sharable user experiences to design desirable motions for humanoid robots in various speechless contexts.

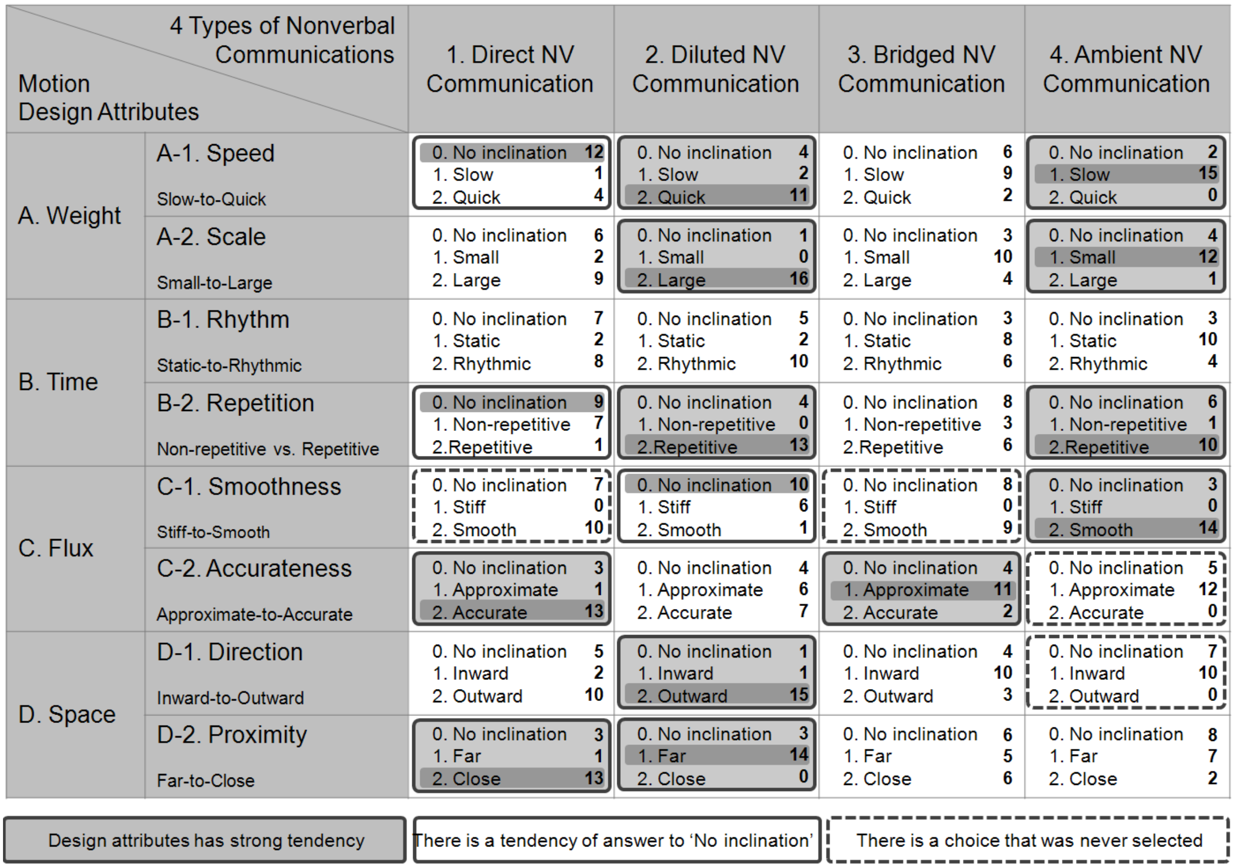
Survey Method

17 masters or doctoral students, 8 males and 9 females from the industrial design department of KAIST, participated in the survey. The survey was composed of four sessions. The first session was an introduction in which participants were acquainted with the purpose of the survey and signed a letter of consent. The second and third sessions were learning sessions. Participants were provided with handouts that explained the concept of nonverbal communication for the second session and motion design attributes for the third session (the content was the same as previous chapters). They carefully read the content so that during the last session they could define the relationship between the two concepts. Participants were provided with a 4x8 matrix (4 types of nonverbal communication x 8 design attributes) on a sheet of paper (Table 2). Each cross section had three possible choices. Two options indicated extreme opposite ends of each design attribute, for example Slow-to-Quick for the speed attribute. If the participants thought that the best speed for ‘Ambient nonverbal communication’ was slow, they circled the word ‘Slow’ on the paper. If the participants had no preference for either option, they could choose the remaining answer, ‘No inclination.’ Participants could refer to the handouts used in the second and third sessions.

Results & Findings

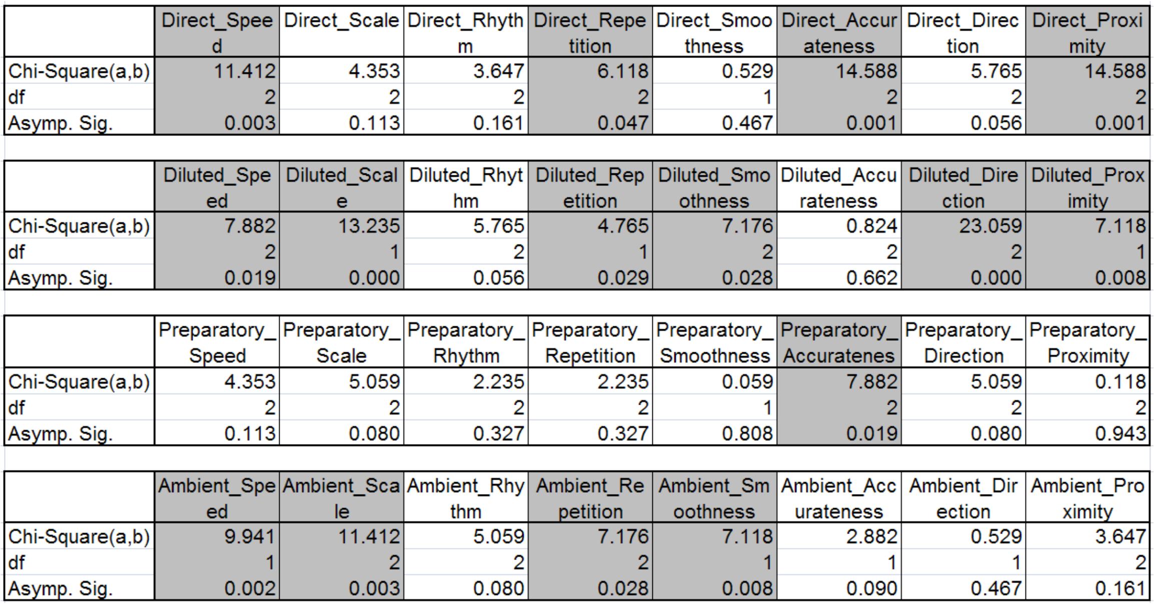
A Chi-square test was used to determine the distribution of the results. If the significant level is lower than $p<0.05$, it can be said that there is a tendency in the responses. If there is no tendency in the responses, it means there is no tendency toward one design attribute. But the tendency of an answer can be different from the tendency of a motion design attribute because ‘No inclination’ was among the three choices. Also, if the answers for an attribute lean toward ‘No inclination,’ then there is no tendency for that design attribute. In the results, 15 of the 32 cross sections were $p<0.05$ (Table 3). Three of those 15 cross sections had a tendency toward ‘No inclination,’ and therefore the remaining 12 cross sections contained the information we wished to identify. There were four more cross sections that we needed to look into even though they were not statistically significant. For ‘direct-smoothness,’ ‘bridged-smooth,’ ‘ambient-accurateness’ and ‘ambient-direction,’ participants showed no tendency for a specific choice. For example, no one selected ‘stiff’ for the ‘direct-smoothness’ relationship (Table 2). This can be interpreted to mean that ‘not stiff’ would be preferential for the motion design in direct nonverbal communication. The remaining cross sections did not show a strong tendency (Table 2). The participants shared their opinions about motion design for each type of nonverbal communication as follows.

1. Direct nonverbal communication needs to be designed with accurate, close motions and without stiff motions.
2. Diluted nonverbal communication needs to be designed with quick, large, repetitive, outward and far motions.
3. Bridged nonverbal communication needs to be designed with approximate motions and without stiff motions.
4. Ambient nonverbal communication needs to be designed with slow, small, repetitive, smooth motions and without accurate, outward motions.



Motion Design Attributes / 4 Types of Nonverbal Communications		1. Direct NV Communication	2. Diluted NV Communication	3. Bridged NV Communication	4. Ambient NV Communication
A. Weight	A-1. Speed Slow-to-Quick	0. No inclination 12 1. Slow 1 2. Quick 4	0. No inclination 4 1. Slow 2 2. Quick 11	0. No inclination 6 1. Slow 9 2. Quick 2	0. No inclination 2 1. Slow 15 2. Quick 0
	A-2. Scale Small-to-Large	0. No inclination 6 1. Small 2 2. Large 9	0. No inclination 1 1. Small 0 2. Large 16	0. No inclination 3 1. Small 10 2. Large 4	0. No inclination 4 1. Small 12 2. Large 1
B. Time	B-1. Rhythm Static-to-Rhythmic	0. No inclination 7 1. Static 2 2. Rhythmic 8	0. No inclination 5 1. Static 2 2. Rhythmic 10	0. No inclination 3 1. Static 8 2. Rhythmic 6	0. No inclination 3 1. Static 10 2. Rhythmic 4
	B-2. Repetition Non-repetitive vs. Repetitive	0. No inclination 9 1. Non-repetitive 7 2.Repetitive 1	0. No inclination 4 1. Non-repetitive 0 2.Repetitive 13	0. No inclination 8 1. Non-repetitive 3 2.Repetitive 6	0. No inclination 6 1. Non-repetitive 1 2.Repetitive 10
C. Flux	C-1. Smoothness Stiff-to-Smooth	0. No inclination 7 1. Stiff 0 2. Smooth 10	0. No inclination 10 1. Stiff 6 2. Smooth 1	0. No inclination 8 1. Stiff 0 2. Smooth 9	0. No inclination 3 1. Stiff 0 2. Smooth 14
	C-2. Accurateness Approximate-to-Accurate	0. No inclination 3 1. Approximate 1 2. Accurate 13	0. No inclination 4 1. Approximate 6 2. Accurate 7	0. No inclination 4 1. Approximate 11 2. Accurate 2	0. No inclination 5 1. Approximate 12 2. Accurate 0
D. Space	D-1. Direction Inward-to-Outward	0. No inclination 5 1. Inward 2 2. Outward 10	0. No inclination 1 1. Inward 1 2. Outward 15	0. No inclination 4 1. Inward 10 2. Outward 3	0. No inclination 7 1. Inward 10 2. Outward 0
	D-2. Proximity Far-to-Close	0. No inclination 3 1. Far 1 2. Close 13	0. No inclination 3 1. Far 14 2. Close 0	0. No inclination 6 1. Far 5 2. Close 6	0. No inclination 8 1. Far 7 2. Close 2

Table 2 Frequency and tendency of the answers



	Direct_Speed	Direct_Scale	Direct_Rhythm	Direct_Repetition	Direct_Smoothness	Direct_Accurateness	Direct_Direction	Direct_Proximity
Chi-Square(a,b)	11.412	4.353	3.647	6.118	0.529	14.588	5.765	14.588
df	2	2	2	2	1	2	2	2
Asymp. Sig.	0.003	0.113	0.161	0.047	0.467	0.001	0.056	0.001

	Diluted_Speed	Diluted_Scale	Diluted_Rhythm	Diluted_Repetition	Diluted_Smoothness	Diluted_Accurateness	Diluted_Direction	Diluted_Proximity
Chi-Square(a,b)	7.882	13.235	5.765	4.765	7.176	0.824	23.059	7.118
df	2	1	2	1	2	2	2	1
Asymp. Sig.	0.019	0.000	0.056	0.029	0.028	0.662	0.000	0.008

	Preparatory_Speed	Preparatory_Scale	Preparatory_Rhythm	Preparatory_Repetition	Preparatory_Smoothness	Preparatory_Accuratenes	Preparatory_Direction	Preparatory_Proximity
Chi-Square(a,b)	4.353	5.059	2.235	2.235	0.059	7.882	5.059	0.118
df	2	2	2	2	1	2	2	2
Asymp. Sig.	0.113	0.080	0.327	0.327	0.808	0.019	0.080	0.943

	Ambient_Speed	Ambient_Scale	Ambient_Rhythm	Ambient_Repetition	Ambient_Smoothness	Ambient_Accurateness	Ambient_Direction	Ambient_Proximity
Chi-Square(a,b)	9.941	11.412	5.059	7.176	7.118	2.882	0.529	3.647
df	1	2	2	2	1	1	1	2
Asymp. Sig.	0.002	0.003	0.080	0.028	0.008	0.090	0.467	0.161

Table 3 Chi-square test results

In the same way that we might appreciate and analyze works of art, we applied our own interpretation to the results. For direct nonverbal communication, accurate motion would be appropriate to express clear messages and close motion would make it easier to communicate without interference. This form of communication in particular should not have stiff motion, because the motion is observed at a close distance and thus the stiffness might detract from the communication. For diluted nonverbal communication, the robot is generally far from the human audience. Therefore, quick, large and outward motion, in other words, high-energy scattering motion, is advantageous to catch the attention of people in distracted contexts such as public spaces or wide-open areas. Moreover, a repetitive motion pattern is necessary because a scattered audience can hardly comprehend the intention of the robot in one instant when catching sight of it by chance. For bridged nonverbal communication, approximate motion would be more natural when presenting the robot as responding unconsciously. But the motion should not be stiff, because stiffness is exactly opposite to natural lifelikeness. In ambient nonverbal communication, the robot’s motion should remain calm and minimized; therefore, low-energy motions (slow and small motions) would be proper. Additionally, smooth and repetitive motion suits the expression of life-likeness as an unconscious state. In that sense, accurate and outward motion is not appropriate.

In spite of the participants’ choices, the statistical analysis and our own interpretation, all of which culminated in recommendations for motion design attributes for different types of nonverbal communication, it is not our intention to constrain designers to following these recommendations. Rather, this study suggests that the designer needs to refer to what people have agreed regarding nonverbal communication and about how memories can be shared, because both sharing information and the reinterpretation of meaning are important to shape a general user-experience.

Conclusion and future works

Knowledge of how to design motions for robots is increasing in importance. Humanoid robots are especially interesting and thus their motions need to be delicately designed to maintain their resemblance to humans. We reviewed related HRI studies about motion, and concluded that we lack knowledge in three areas: 1. nonverbal motion design, which is critical for HRI experiences with a physical humanoid robot; 2. motion design from a user-centered point of view; 3. practicality to help designers create motions for humanoid robots. To overcome these limitations, we turned to user-centered design approach. Based on the relationship between design attributes and nonverbal communication experiences, we suggest the concept of nonverbal communication gestalt to design a general user experience for interaction with a humanoid robot. To test our concept, a survey with 17 participants was conducted and it was found that participants shared a considerable amount of design preferences for desirable nonverbal communication with humanoid robots. Nevertheless, we do not seek to impose the relationships extracted here as a design guideline, instead preferring to leave open the possibility for reinterpretation, which is the spirit of art and design. As the HRI field grows, additional contributions to the study of robot design are required to bring robot technology into people's daily lives. This study aims to make synergetic knowledge about motion for robot engineering and design available so that people can have more desirable HRI experiences soon.

In this paper, we have introduced a concept user-centered motion design for humanoid robots. However, a real robot platform needs to be implemented for experimental verification of the concepts outlined in this paper. We plan to conduct a motion design case study with real humanoid robots so that we can identify deeper insights and inspirations.

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