Quantification of Elegant Motions for Receptionist Android Robot

Makoto Ikawa[2], Etsuko Ueda[1](✉), Akishige Yuguchi[2], Gustavo Alfonso Garcia Ricardez[2], Ming Ding[2], Jun Takamatsu[2], and Tsukasa Ogasawara[2]

[1] Osaka Institute of Technology, Osaka, Japan
etsuko.ueda@oit.ac.jp
[2] Nara Institute of Science and Technology, Nara, Japan

Abstract. To improve the general image of robots, in this study we describe a method of achieving "elegant motions based on women's sense" in an android robot. There have been many books published in Japan containing advice for women on how to have elegant manners. Our approach was to quantify the elegant motions that are qualitatively expressed in these etiquette books, using an android robot. In this research, we focused on arm- and face-based motions, such as giving directions, with an emphasis on "reception" tasks. We programmed the robot to perform desirable motions, such as "show the palm to a guest and do not raise the hand higher than the shoulder," which are commonly expressed in the manners books. For each implemented motions, many patterns could be generated by changing certain parameters, such as the movement speed, the angle of the arm and the hand, and the distance and angle to the indicated location. We verified these motions using a subjective evaluation and discussed the elegant and quantified motions based on the result.

Keywords: Elegant motion · Android robot · Human-robot interaction

1 Introduction

With the ever-expanding market for service robots in Japan, the level of interaction between robots and human is also increasing. Robots employed in this field are required to establish a good relationship with humans in various situations of daily life. To achieve this, the robots need to be accepted by people from all walks of life and both genders. To assist in yielding this outcome, the androids must learn how to display elegant behavior, which is one of the main criteria by which people accept others in human society.

There is a great deal of activity in the research field on movement and human psychology. For example, there has been a paper on human-friendly speed patterns and delivery positions in hand-over actions [1], a study on the generation of robotic movements in humans [2], and a proposal for a robotic system that

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can perform movements to effectively cooperate with humans [3]. In addition, we have seen studies in which android robots that are capable of facial expressions have been employed in face-to-face selling [4], as receptionists, and in school education [5].

However, there are only few cases that have examined the "beauty" or "elegance" of robot motion. To address this, we herein attempt to improve the general impression of robots by implementing "elegant robot motions that based women's perception." More specifically, we will describe how we quantified the elegant motions of an android robot when performing "pointing actions" in its role as a receptionist.

2 Elegant Behavior

Many etiquette books for women have been published in Japan, with their contents being widely accepted as indicating desirable behavior. In this research, we therefore treated the descriptions in these texts as denoting the gold standard of elegant motions. We collated the common features of elegant motions that were frequently described in different books, implemented motions in android robots, performed subjective evaluations, and quantified the qualitative features of elegant motions based on the results.

We studied descriptions of elegant motions contained in nine etiquette books [6–14] published in Japan. Table 1 shows examples of the qualitative definition of elegant motions extracted from these publications.

Table 1. Examples of elegant behavior

Motion	Description	Ratio[%]
Pointing	Extend fingertips neatly	100
	Show the palm to the guest	28.6
	Point the palm diagonally upward	14.3
	Arm should not be raised above the shoulder	14.3
	Point the front of the body toward the guest	14.3
Passing and receiving objects	Pass objects with both hands	87.5
	Face the guest side in front	62.5
	Pass objects with arc trajectory	12.5
	Close the fingers	12.5
	Tighten both side so as not to open up too much	12.5
Turning around when being called	Turn the whole or upper body	100
	Turn around slowly	75
	Turn shoulder before turning face	50

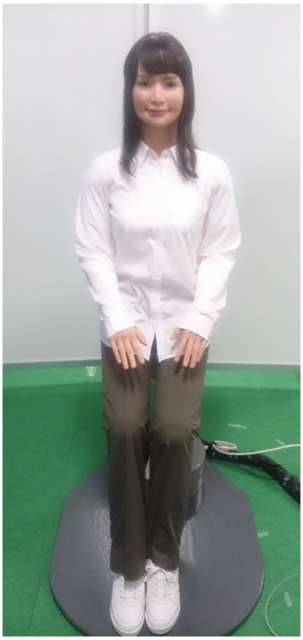

Fig. 1. Actroid SIT

Table 2. Movable parts (for pointing action)

Movable parts	Motions
Left arm	Hand twisting
	Elbow bending
	Open-close movement of shoulder
	Arm twisting
	Open-close movement of side
	“Fall in” pose
Right arm	Open-close movement of shoulder
	Rotation of upper arm
Waist	Rotation
Neck and Head	Neck bending
	Head turning

3 Implementation of Elegant Motions to an Android Robot

In this research, we used the Actroid SIT, which is an android robot manufactured by KOKORO Co., Ltd. Figure 1 gives an overview of Actroid SIT. This robot’s body is coated with silicon, making it closely resemble a human. Actroid SIT has 42 degrees of freedom and is driven by pneumatic actuators. Table 2 shows the movable parts used in the “pointing task”, which is the focus of this research.

The robot’s task was to point to a sign printed on a sheet of A4 paper with the legend “Venue entrance” written on it in Japanese, as shown in Fig. 2. The sign was situated higher than the robot’s waist and set so that its top would be pointed at when the hand position was at its highest. Figure 3 indicates the details of the relative location between the sign and the robot. The sign was 101 cm from the floor to the bottom edge of the sign and 11.5 cm from the edge of the partition to the sign. The bottom left corner of the sign was located 45 cm from the android’s left wrist, while the top left corner was located 40 cm from the left shoulder and the bottom edge was 12.5 cm from a line extending horizontally from the robot’s waist.

We selected the following two features from the definition in Table 1 for quantification:

Fig. 2. Pointing action

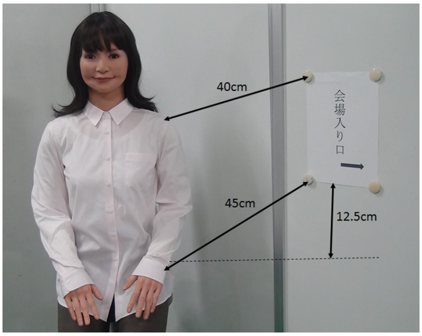

Fig. 3. Location of robot and sign

(a) Rotation of forearm (b) Angle between forearm and upper arm

Fig. 4. Controlled angle

1. For the feature that “the palm faces the guest and the palm direction is diagonally upward,” the forearm rotation angle (shown in Fig. 4(a)) was quantified.
2. For the feature that “the arm should not rise above the shoulder,” the angle formed by the upper arm and forearm (shown in Fig. 4(b)) was quantified.

By controlling these angles, a plurality in the pointing motion was generated. The implementation procedure for the robot motion is described below.

Step 1. Start pose, target pose, and intermediate pose were generated using a motion creation software (Fig. 5).
Step 2. Cubic spline interpolation was performed between these three poses and each joint angle at each time was obtained.
Step 3. The speed of motion between each posture generated in Step 2 was determined. It had been observed in a previous study that the arm velocity of the reaching movement described a “bell” shape [15]. This was reflected in the present experiment after manually adjusting the movement speed.

(a) Start pose (b) Intermediate pose (c) Target pose

Fig. 5. Keyframe posture

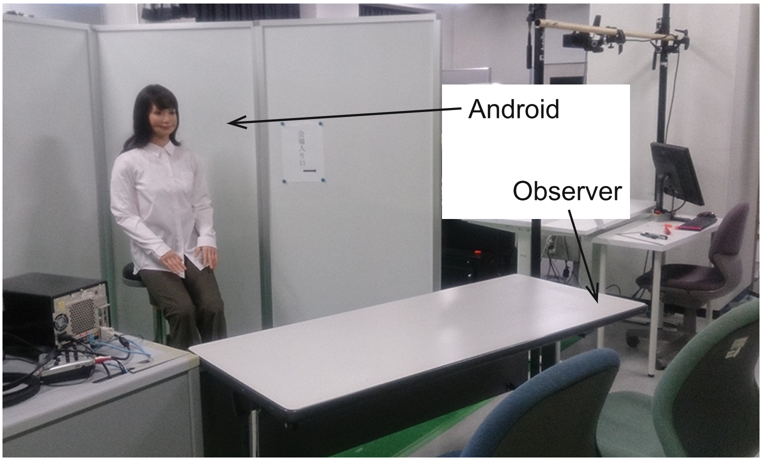

Fig. 6. Experimental environment

4 Subjective Evaluation

4.1 Evaluation Method

The observer was sitting facing the android, as shown in Fig. 6, and observed the robot's generated motion. The observed motion was evaluated using Thurston's pairwise comparison method and the SD method. The observers comprised five men and five women aged from their 20 s to 40 s.

In this experiment, robot behaviors originated from five patterns of different (1) angles of rotation of the forearm and (2) angles of the upper arm and forearm were presented, with the observers performing the following evaluations:

1. Pairwise comparison: All combination pairs were compared and participants selected the motion that they considered the most "elegant" in each trial.
2. SD method: The observers evaluated each motion on a 5-point scale using adjective pairs of "elegant - vulgar," "smooth - awkward," "polite - rude," "beautiful - ugly," and "fast - slow."

(1) α =90[deg]

(2) α =67[deg]

(3) α =45[deg]

(4) α =23[deg]

(5) α =0[deg]

Fig. 7. Five pointing motions with various palm directions

4.2 Subjective Difference with Variation of Palm Direction

By changing the rotation angle of the forearm to 90 [deg], 67 [deg], 45 [deg], 23 [deg], and 0 [deg], the robot presented five motions with different palm directions. The target poses in each motion are shown in Fig. 7. In these motions, the angle between the upper arm and forearm was fixed at $\theta = 150$ [deg].

Table 3 shows the results of the pairwise comparison. Numerical values are given horizontally, denotes the "9" (row = 90, column = 67) the number of people who evaluated that 90 [deg] was more elegant when comparing 90 [deg] and 67 [deg]. Figure 8 shows the scale value of the elegance calculated from the comparison result using Thurston's method. This value indicates that elegance became greater as it increased in the positive direction. Based on Fig. 8, the movement was most elegant when the rotation angle of the forearm was 90 [deg], with the quality decreasing as the angle decreased from that position.

Table 3. Result of pairwise comparison (palm direction)

		B				(deg)
		90	67	45	23	0
A	90	-	9	10	10	10
	67	1	-	8	10	10
	45	0	2	-	9	10
	23	0	0	1	-	9
	0	0	0	0	1	-

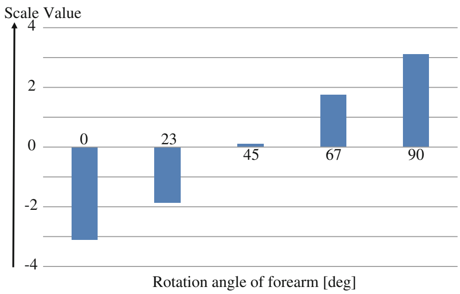

Fig. 8. Scale value of "elegance" (palm direction)

Figure 9 shows the results of subjective evaluation using the SD method. Factor analysis was performed using the evaluation results from the ten observers. Those with an eigen value of 1 or more were extracted as a common factor and the factor loadings were obtained by Promax rotation. Table 4 shows the calculated factor loadings. From Table 4, in the first factor, the factor loadings of the adjective pairs of "beautiful vs. ugly," "elegant vs. vulgar," and "polite vs. rude" were high. It could be said that the first factor represents "gracefulness"; likewise, it can be said that the second factor is a factor concerning "smoothness." Figure 10 shows the factor score of the first factor at each angle, while Fig. 11 shows the factor score of the second factor at each angle. From Fig. 10, the highest level of "elegance" was seen at 90 [deg], while according to Fig. 11, the smoothest angle was 67 [deg].

4.3 Subjective Difference with Variation of Hand Height

By changing the angle between the upper arm and the forearm to 180 [deg], 165 [deg], 150 [deg], 135 [deg], and 120 [deg], the robot presented five motions with

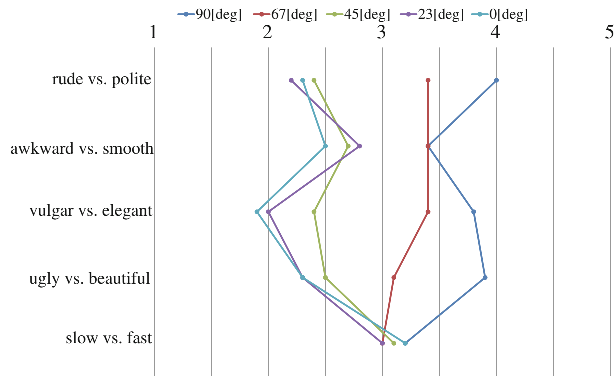

Fig. 9. SD profile (palm direction)

Table 4. Factor loading (palm direction)

	1st factor	2nd factor
Beautiful vs. ugly	0.888	−0.101
Elegant vs. vulgar	0.879	0.004
Polite vs. rude	0.829	0.256
Smooth vs. awkward	0.298	0.505
Fast vs. slow	0.163	−0.403

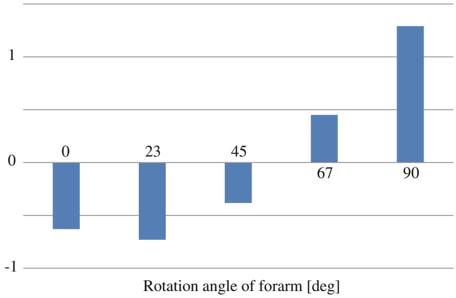

Fig. 10. Factor score of 1st factor (palm direction)

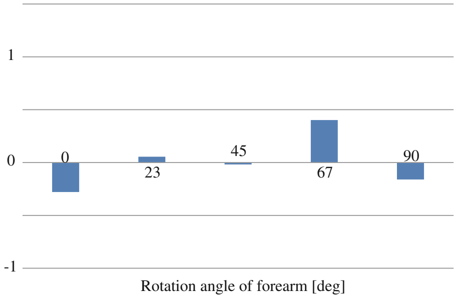

Fig. 11. Factor score of 2nd factor (palm direction)

different hand heights. The target poses in each motion are shown in Fig. 12. In these motions, the rotation angle of the forearm was fixed at $\alpha = 90$ [deg].

Table 5 shows the results of the pairwise comparison and Fig. 13 shows the scale value of elegance. Based on the pairwise comparison, the robot was most elegant when the angle between the upper arm and forearm was 135 [deg]; it transpired that the angle between 135 [deg] and 150 [deg] appeared elegant.

(1) $\theta = 120$[deg]

(2) $\theta = 135$[deg]

(3) $\theta = 150$[deg]

(4) $\theta = 165$[deg]

(5) $\theta = 180$[deg]

Fig. 12. Five pointing motions with various hand heights

Table 5. Results of pairwise comparison (palm direction)

		B				(deg)
		180	165	150	135	120
A	180	-	4	2	4	5
	165	6	-	6	4	5
	150	8	4	-	7	9
	135	6	6	3	-	10
	120	5	5	1	0	-

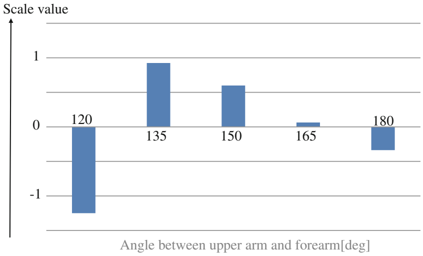

Fig. 13. Scale value of "elegance" (hand height)

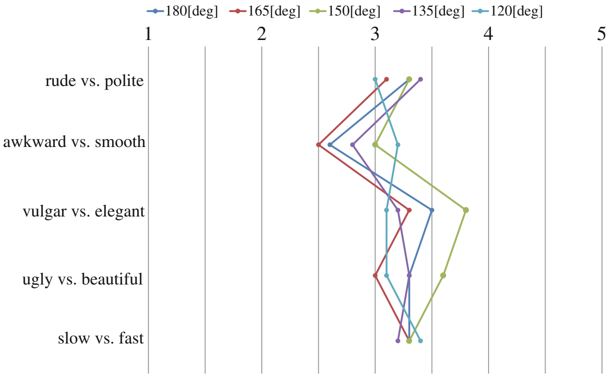

Fig. 14. SD profile (hand height)

Figure 14 shows the results of the impression evaluation using the SD method. Factor analysis was performed using the evaluation results for the ten observers, as in the previous section. Table 6 shows the calculated factor loadings.

Based on Table 6, in the first factor, the factor loadings of the adjective pairs of "beautiful vs. ugly," "elegant vs. vulgar," and "polite vs. rude" were high. It

Table 6. Factor loading (hand height)

	1st factor
Beautiful vs. ugly	0.882
Elegant vs. vulgar	0.769
Polite vs. rude	0.559
Smooth vs. awkward	0.335
Fast vs. slow	−0.351

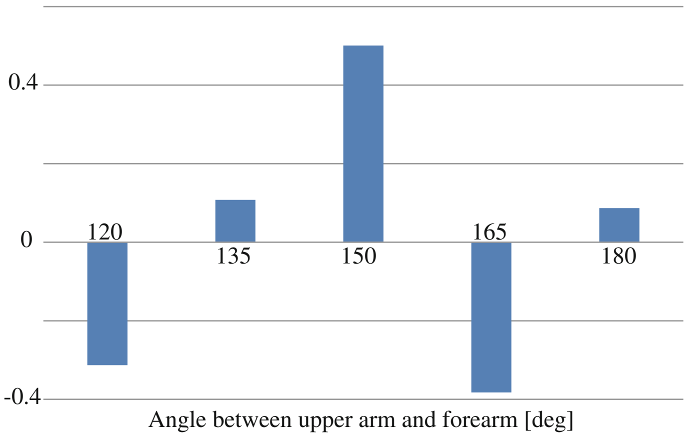

Fig. 15. Factor score (hand height)

could be stated that the first factor represents "gracefulness." Figure 15 shows the factor score of the first factor at each angle.

From Fig. 15, it can be established that the robot was most "elegant" when the angle between the forearm and upper arm was 150 [deg].

5 Conclusion

By changing the rotation angle of the forearm, and the angle between the upper arm and forearm, we made the android robot to perform various motions. From the results of the ten observers' impression evaluations of these motions, we quantified the features of elegant motions. The results of the evaluation showed that the most elegant pointing motion of the Actroid SIT was achieved when the rotation angle of the forearm was 90 [deg] and the angle of the upper arm and forearm was between 135 [deg] and 150 [deg].

In the future, we will further analyze differences in impression due to the gender gap and the appearance of the robot. We will also compare the motions of humans and androids in terms of beauty.

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