Identification of Gracefulness Feature Parameters for Hand-Over Motion

Etsuko Ueda[1(✉)], Kenichi Iida[2], Kentaro Takemura[3], Takayuki Nakamura[4], and Masanao Koeda[5]

[1] Osaka Institute of Technology, Osaka, Japan
etsuko.ueda@oit.ac.jp
[2] National Institute of Technology, Nara College, Nara, Japan
[3] Tokai University, Kanagawa, Japan
[4] Wakayama University, Wakayama, Japan
[5] Osaka Electro-Communication University, Osaka, Japan

Abstract. As robots in the welfare and service industries must come into contact with humans, they are required to make favorable impressions on human sensibilities. Our research focuses on the concept of "graceful motion," as defined by Hogarth. In order to implement graceful motion in robots, we analyze the hand trajectories which highly skilled servers generate in the task of passing a wine glass to extract graceful and ungraceful curve features. We propose to model the hand trajectory by a polynomial of the fourth degree and to adjust the S-shaped curvature of the hand trajectory. An impression evaluation is then conducted, which indicates that a $20\,\% - 60\,\%$ S-shaped curvature correspond to gracefulness in a hand-over motion; this parameter corresponds to Hogarth's definition.

Keywords: Graceful motion · Motion capture · Human-robot interaction

1 Introduction

Robot applications are entering fields that require close contact with humans, for example, the welfare and service industries. In these fields, the impressions made by robots during human-robot interactions are more important than efficiency. In an environment where humans and robots coexist, the exhibition of human-like behavior by robots makes a favorable impression on human sensibilities, because such behavior generates a sense of safety. Although there are many factors involved in the expression of humanity by robots, we focus on robot motion.

Many researchers have investigated methods to develop human-like motion in robots. For example, Zhang [1] has focused on cooperative motion between two humans in order to identify the characteristics of human-like motion, with a view to application in robots. Kanda [2,3] has analyzed human impressions of human-robot interactions. Yokoi [4] has investigated the manner in which robot motions

M. Kurosu (Ed.): HCI 2016, Part II, LNCS 9732, pp. 115–124, 2016.
DOI: 10.1007/978-3-319-39516-6_11

can positively reassure a human observer. Important studies focusing on human hand motion and its trajectories have also been conducted. For example, Atkeson and Hollerbach [5] have determined that the hand tip trajectory is approximately linear, and that the velocity trend for human multi-joint movement exhibits a bell shape. Hence, Flash and Hogan [6] have proposed the minimum-jerk model as a means of reproducing these features. Further, Uno [7] has proposed the minimum-torque-change model, which considers the body kinematics. Unfortunately, as far as we know, a precise model of human-like motion has not yet been developed.

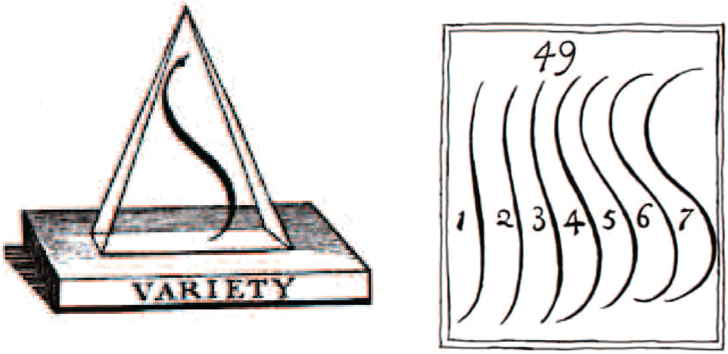
Schiller [8] has stated that "grace is the beauty of action and can be applied to unbeautiful appearances." This statement suggests that the appearance of any motion can be made graceful through refinement of that motion. Moreover, "gracefulness" is a characteristic inherent in human motion. Therefore, we can assume that robot motions can be made to appear more human-like through improved gracefulness.

In this study, we identify the gracefulness feature parameters in a hand-over motion and develop a model for generation of graceful trajectories. We first quantify William Hogarth's definition of graceful motion, which will be discussed below. Then, the graceful hand trajectories (S-curves) involved in the passing of a wine glass are analyzed to determine whether or not they conform to the "line of beauty" defined by Hogarth. Hence, we model graceful hand trajectories and identify their parameters, so as to achieve a model that facilitates automatic graceful trajectory generation.

2 The "Line of Beauty" and Modeling of Grace Hand Trajectory Using Quartic Equation

Graceful motion has been defined qualitatively by both William Hogarth and Frederik Jacobus Johannes Buytendijk [9], and this study focuses on Hogarth's definition in particular. Figure 1(a) shows the "line of beauty" presented in the cover art of Hogarth's book, "The Analysis of Beauty [10]." Hogarth suggested that S-shaped lines (serpentine lines) appear beautiful and graceful. Discussing examples of various S-shaped curves (Fig. 1(b)), he stated that: "Strictly speaking, there is but one precise line, properly to be called the line of beauty, which in the scale of them Fig. 1(b) is number 4: the lines 5, 6, 7, by their bulging too much in their curvature becoming gross and clumsy; and, on the contrary, 3, 2, 1, as they straighten, becoming mean and poor." Therefore, according to Hogarth, line number 4 in Fig. 1(b) can be considered to be a "line of beauty."

In this study, we focus on the task of "passing a wine glass," considering the gracefulness of the hand trajectory. The S-shaped curvature of the hand trajectory determined the gracefulness, in accordance with Hogarth's "line of beauty." We consider that skilled servers working at a hotel constantly exhibit graceful motion, because these individuals are very conscious of their mannerisms and are trained to make a favorable impression on hotel clients. In our experiment, four people who had been educated at a particular school for hotel staff (Subjects 1–3: male, Subject 4: female) were taken as subjects. These individuals performed the



(a) "The Analysis of Beauty" cover art (b) Various S-curve shapes

Fig. 1. Line of beauty defined by William Hogarth

motion of "passing a wine glass" three times. Their motions were measured via motion capture, using the MVN BIOMECH full-body human measurement system (Xsens Co. USA), which incorporates inertial sensors, biomechanical models, and sensor fusion algorithms. The sampling rate was 120 Hz.

Figure 2 shows a sample "passing a glass" motion. The real trajectory of one such motion is a three-dimensional (3D) curve. In order to analyze these movements simply, we focused on the plane in which each subject performed, and then converted the 3D trajectory into a two-dimensional (2D) curve. This plane was extracted by conducting a principal component analysis of the real hand

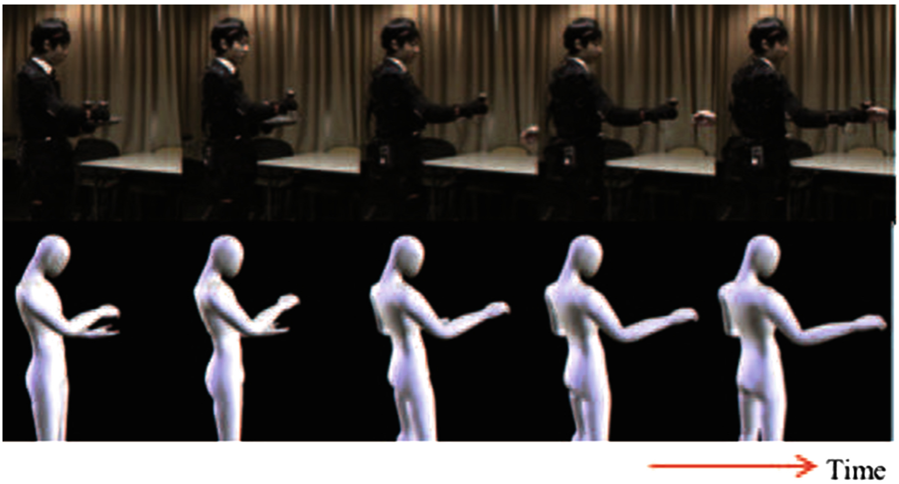


Fig. 2. Example of wine-glass passing motion

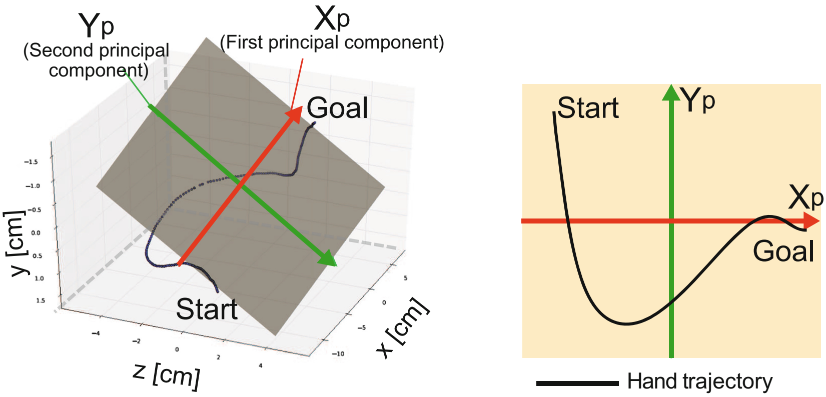


Fig. 3. Motion characteristics plane and projected hand trajectory

trajectory. The plane was comprised of the first (x-axis) and second (y-axis) principal components, and was defined as the “motion characteristics plane.” The 2D curve was then obtained by projecting the 3D trajectory onto the motion characteristics plane, as shown in Fig. 3. We approximated this projected trajectory using a polynomial of the fourth degree. These coefficients are obtained by the least squares method. The right-hand trajectory was thus expressed as

$$y = a_4x^4 + a_3x^3 + a_2x^2 + a_1x + a_0, \tag{1}$$

where the $a_{0\sim4}$ terms are coefficients.

Our previous research [11] has shown that graceful motions have an inflection point, where the shape of the trajectory changes from concave down to concave up. Therefore, these trajectories are considered to be S-shaped. Furthermore, our previous findings indicate that motions performed in crosswise directions are superior to those in vertical directions, as regards perception of gracefulness. The simulation results obtained in that study indicate that motion in a 45° oriented plane produce the most favorable impression on human observers.

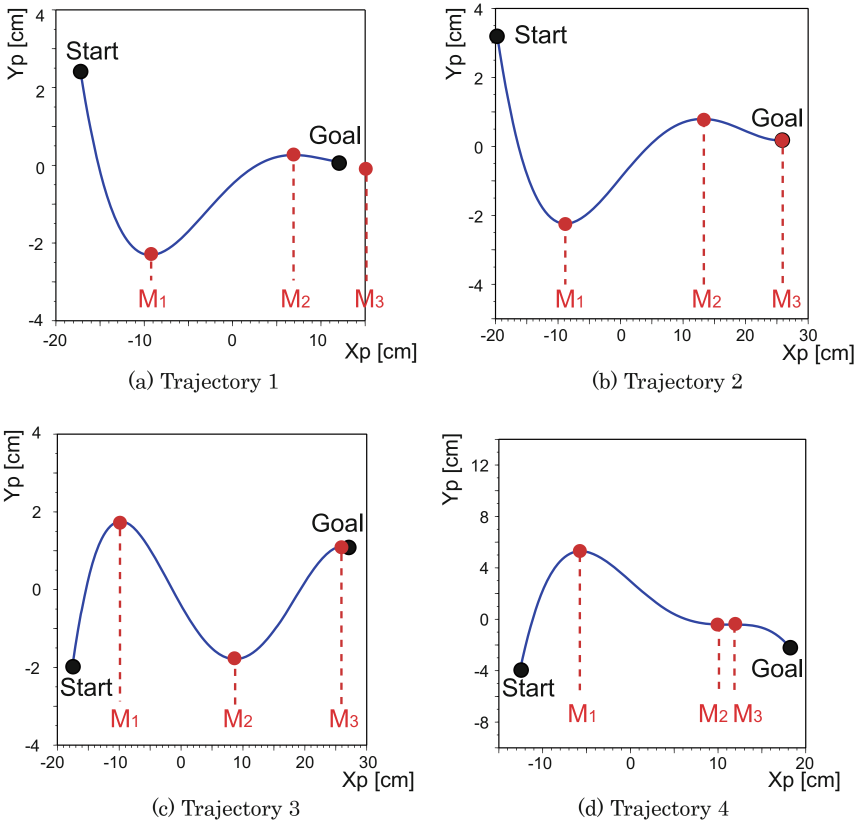
This paper aims to identify the shape parameters of the S-curve corresponding to graceful hand trajectories. It is difficult to control the shape of the S-curve by simultaneously adjusting the $a_0 \sim a_4$ coefficients of the quartic equation (Eq. (1)). Therefore, we propose the use of the local extremum value to control the S-shaped curve. By differentiating Eq. (1), we obtain

$$y' = A(x - M_1)(x - M_2)(x - M_3), \tag{2}$$

where A is an arbitrary constant and M_1, M_2, and M_3 are the x-values at which the y-value is a local extremum. Note that $M_1 < M_2 < M_3$.

Figure 4 shows examples of 2D hand trajectories with graceful S-curve features and their M_1, M_2, and M_3 values. By integrating Eq. (2), we obtain

$$y = A(Bx^4 + Cx^3 + Dx^2 + Ex) + F, \tag{3}$$



(a) Trajectory 1 (b) Trajectory 2

(c) Trajectory 3 (d) Trajectory 4

Fig. 4. Two-dimensional trajectories with S-shaped features

where, $B = 1/4$, $C = (M_1 + M_2 + M_3)/3$, $D = (M_1M_2 + M_2M_3 + M_1M_3)/2$, and $E = -M_1M_2M_3$. However, the A and F coefficients are undefined. As the start (x_s, y_s) and goal (x_g, y_g) points are fixed, A and F can be determined by utilizing these points as constraints. Thus, we obtain our proposed S-curve model, where

$$A = \frac{y_s - y_g}{B({x_s}^4 - {x_g}^4) + C({x_s}^3 - {x_g}^3) + D({x_s}^2 - {x_g}^2) + E(x_s - x_g)}, \tag{4}$$

$$F = y_s - A(B{x_s}^4 + C{x_s}^3 + D{x_s}^2 + Ex_s). \tag{5}$$

3 S-Curve Shape Control

In Eq. (2), the S-shaped curvature of the hand trajectory can be changed by fixing M_1 and M_3 and adjusting M_2. Thus, the y-value of M_1 (or M_3) can be controlled by M_2 alone. Figure 5 shows S-shape deformation results obtained by

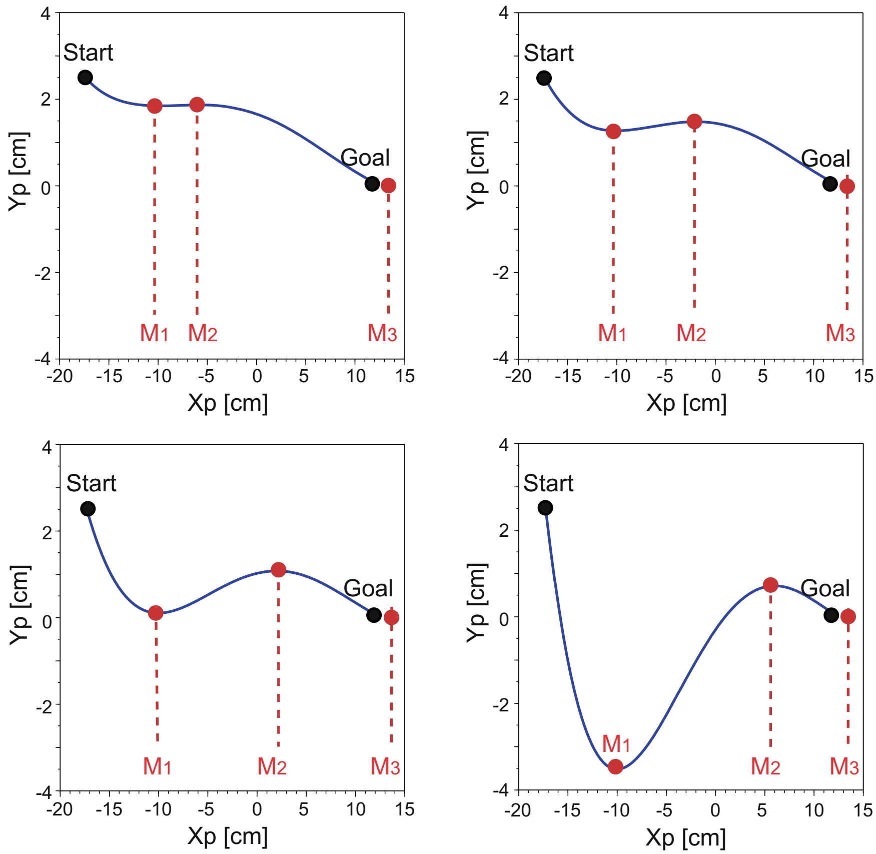
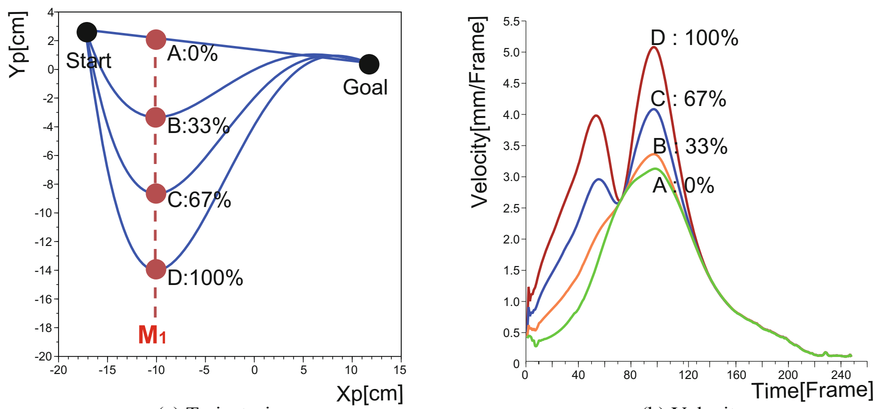


Fig. 5. S-shaped curvature control by adjusting M_2



(a) Trajectories (b) Velocity

Fig. 6. Generated curves and corresponding velocities

adjusting M_2 for the trajectory in Fig. 4(a). Note that the S-shaped curvature is one of the parameters of gracefulness, as defined by Hogarth in terms of the curves shown in Fig. 1. By adjusting M_2 with fixed M_1 and M_3, the S-shaped curvature of the hand trajectory can be changed.

Figure 6(a) shows sample generated trajectories, while Fig. 6(b) shows the change in velocity of each trajectory in Fig. 6(a). The "0 % point" is the intersection of the line between (x_s, y_s) and (x_g, y_g) with the line $x = M_1$ (or M_3). The "100 % point" is the greatest y-value extension the hand trajectory can achieve when the x-value is M_1 (or M_3). As indicated by Fig. 6, each trajectory has a different length. Thus, the peak movement velocities differ if the movement duration is constant, which would affect the observer impressions of the motion. To avoid this effect, we adjusted the movement duration to conform to the obtained motion's peak velocity. Figure 7 illustrates the adjusted results.

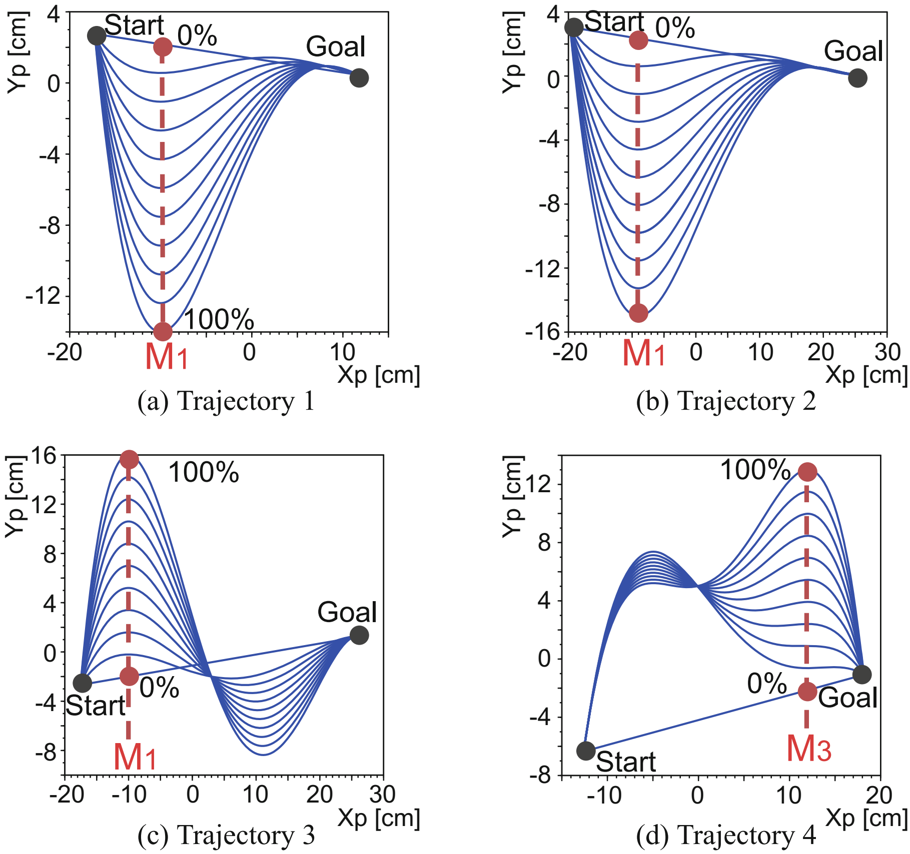


Fig. 7. Trajectory generation

4 Impression Evaluation

In total, 11 trajectories (with different S-shaped curvature) were generated for each trajectory in Fig. 4, using the proposed S-curve model. Figure 7 shows the generated trajectories. The "0 % point" and "100 % point" were defined as in the previous section. Various curvatures were calculated, in 10 % increments between the 0 % and 100 % points. In this paper, we refer to each trajectory as "n% curvature trajectory." An impression evaluation of the two trajectories (Fig. 7(a) and (c)) was then conducted using the Thurstone's paired comparison method [12]. The number of observers was seven. To evaluate the observers' impressions of the trajectories, 3DCG was used to recreate the motion of a waiter "passing a glass," employing the 11 obtained trajectories. Figures 8 and 9

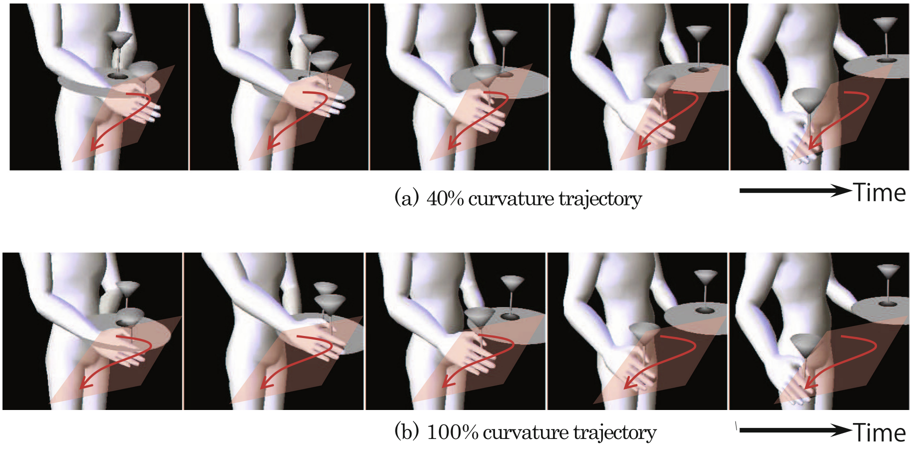


Fig. 8. Generated motion 1

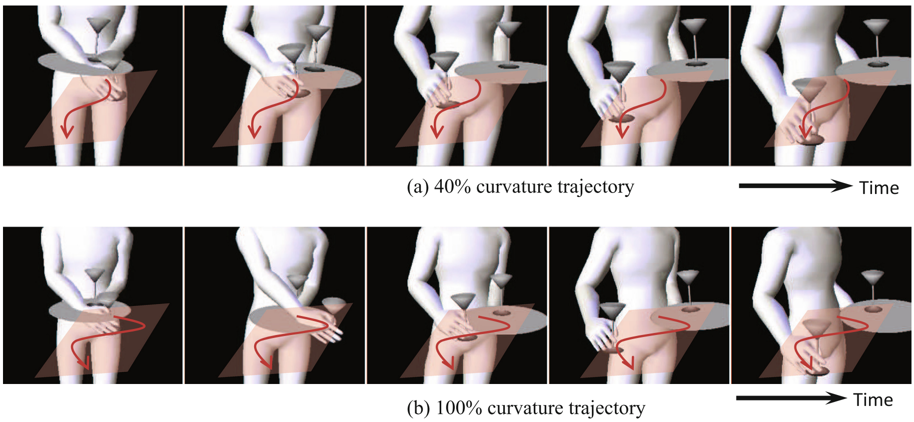


Fig. 9. Generated motion 3

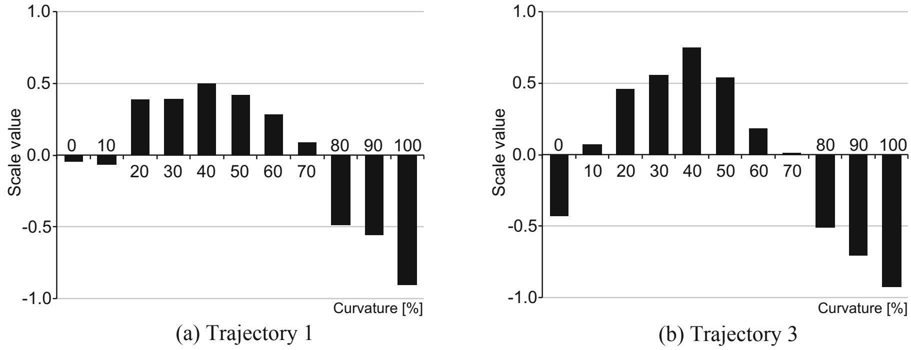


Fig. 10. Impression evaluation results (Thurstone's scale values)

show examples for the motions with 40 % and 100 % curvature trajectory in Fig. 7(a) and (c), respectively, while Fig. 10 shows the impression evaluation results for these motions. The vertical scale in Fig. 10 represents the Thurstone's scale values. These values indicate the gracefulness.

As Fig. 10 indicates, the 40 % curvature trajectory yields the best impression, and this impression decreases with curvatures further from 40 %. Hence, it was determined that a 20 % ∼ 60 % curvature trajectory corresponds to perceived gracefulness in hand-over motions. Through these experiments, we confirm that this parameter corresponds to Hogarth's definition of the "line of beauty," and the validity of our modeling method of the graceful hand trajectory.

5 Conclusions

This paper attempted to identify the parameters of gracefulness through analysis of the motion involved in passing a wine glass, and proposed a method for adjusting the S-shaped curvature of a hand trajectory by controlling the extremum. Our research results (both from this study and a previous report) suggest that the trajectory that satisfies the following conditions can produce an impression of gracefulness for observers of a serving task:

1. The motion characteristics plane should be oriented at 45°.
2. The S-shaped curvature is 20 % to 60 %.

In the next stage of our research, we will confirm the validity of the proposed modeling method through application to other tasks. The effective modeling of graceful movements will allow robots to replicate this behavior, thereby increasing human acceptance of their presence.

Acknowledgment. This work was supported by JSPS KAKENHI Grant Number 26330322.

References

1. Zhang, N., Ikeura, R., Wang, Y., Mizutani, K., Sawai, H.: Characteristics of the human arm based on a musculoskeletal model of cooperative motion between two humans. J. Biomech. Sci. Eng. **3**(1), 50–61 (2008)
2. Kanda, T., Ishiguro, H., Imai, M., Ono, T.: Body movement analysis of human-robot interaction. In: Proceedings of the 18th international joint conference on Artificial intelligence, pp. 177–182 (2003)
3. Kanda, T., Miyashita, T., Osada, T., Haikawa, Y., Ishiguro, H.: Analysis of humanoid appearances in human-robot interaction. IEEE Trans. Robot. **24**(3), 725–735 (2008)
4. Yokoi, K., Arisumi, H., Komoriya, K.: Gentle motion of robot manipulator - how does human feel hand-over motion of a robot? J. Mech. Eng. Lab. **52**(4), 149–155 (1998)
5. Atkeson, C.G., Hollerbach, J.M.: Kinematic features of unrestrained vertical arm movements. J. Neurosci. **5**(9), 2318–2330 (1985)
6. Flash, T., Hogan, N.: The coordination of arm movements: An experimentally confirmed mathematical model. J. Neurosci. **5**(7), 1688–1703 (1985)
7. Uno, Y., Kawato, M., Suzuki, R.: Formation and control of optimal trajectory in human multijoint arm movement. Biol. Cybern. **61**(2), 89–101 (1989)
8. Schiller, J.C.F., Über Anmut und Würde. Neue Thalia, vol. 2 (1793)
9. Buytendijk, F.J.J.: Allgemeine Theorie der Menschlichen Haltung und Bewegumg. Springer, Heidelberg (1972)
10. Hogarth, W.: The Analysis of Beauty: Written With a View of Fixing the Fluctuating Ideas of Taste. Georg Olms Verlag, New York (1974). https://books.google.co.uk/books?id=szQGAAAAQAAJ
11. Tanaka, T., Tsuduki, T., Ueda, E., Takemura, K., Nakamura, T.: Modeling of graceful motions: determining characteristics of graceful motions from handover motion. In: Computational Methods and Experimental Measurements XVI, vol. 55, pp. 453–463. WIT Transactions on Modeling and Simulation (2013)
12. Thurstone, L.L.: Psychophysical analysis. Am. J. Psychol. **38**(3), 368–389 (1927)