Design and Evaluation of Handover Movement Informing Receiver of Weight Load

Takafumi Matsumaru

Abstract

This paper presents the study results on the handover movement informing a receiver of the weight load as an example of the informative motion for the human-synergetic robot. To design and generate the movement depending on the weight load, the human movement is measured and analyzed, and four items are selected as the parameter to vary – the distance between target point and transferred point (in front-back direction), the distance between highest point and transferred point (in vertical direction), the elbow rotation angle, and the waist joint angle. The fitted curve of the parameter variation depending on the weigh load is obtained from the tendency of the subjects' movement data. The movement data for an arbitrary weight load is generated processing the standard data at $0\ kg$ of weight load so that each parameter follows the fitted curve. From the questionnaire survey, although it is difficult for a receiver to estimate the exact weight load, he may distinguish the heavy weight load from the light weight load so that the package will be received safely and certainly.

Keywords: Human-Synergetic Robot, Informative Motion, and Handover Task

1 Introduction

This paper presents the study results on the handover movement informing a receiver of the weight load as an example of the informative motion [1] for human-synergetic robots.

During the handover movement of a package among people, the deliverer operates in a manner that some information, such as the weight and character of the package to pass, is transmitted to a receiver regardless whether it is intentional or unconscious. The receiver can prepare for his action observing the deliverer's operation and reading out a certain information without oral communication so that the package is received safely and certainly. Such kind of the form and structure or the movement and function including some unexplicit information is collectively called "informative motion". Facing an aging society coupled with a declining birthrate, the activity of human-synergetic robots working in cooperation with people in the same living space and workspace as people will play an important role in the near future. The informative motion should be taken into consideration to design the form and movement of the human-synergetic robot so that it will not make those around feel a sense of incongruity. This research takes up the handover movement of a package aiming to make the task from a robot to a person more natural by measuring and analyzing the movement between two people, clarifying the features of variance of movement depending on the weight load, and implementing them into the robot movement.

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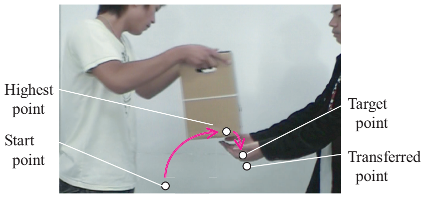


Figure 1: Handover task

2 Measurement and Analysis of Human Movement

In order to investigate the feature of the human handover movement, the handover movement of a package, $L185$-$W340$-$H320$ mm in size and 0 (empty), 2, 5, 10, and 15 kg in the same appearance, between two people is measured as shown in Fig. (1).

2.1 Analysis result

The subjects are nineteen male students in their early twenties. The difference from the reference data at 0 kg of weight load is considered in each subject to examine the variance depending on the weight load, since the data varies greatly among individuals. (1) *Distance between target point and transferred point (in front-back direction):* Although there are great differences between subjects, it has a general tendency that the distance is longer as the weight becomes heavier. It shows that a heavier package is presented more closely to the receiver's body. (2) *Distance between highest point and transferred point (in vertical direction):* There is a tendency that the difference in height is larger as the weight becomes heavier in general. It shows that a heavier package is transported over longer distance until released after lifted up. (3) *Height to start movement:* Although there are great differences between subjects, the height to start movement is almost constant regardless of the weight, or the height is lower as the weight becomes heavier, in many subjects. (4) *Movement speed of hand:* Taking the maximum speed in vertical direction, it shows a rough tendency that the downward (negative) speed is larger as the weight becomes heavier. (5) *Elbow rotation angle:* There is a tendency that the average during the movement is larger as the weight becomes heavier broadly. It shows that a heavier package is transferred with his elbow raised and the bodily side opened. (6) *Waist joint angle:* Looking at the max-min difference during the movement, it has a rough tendency that the difference is larger as the weight becomes heavier. It shows that the upper part of body is moved more greatly to transfer a heavier package.

2.2 Discussion

At the most of the noted points, the variance depending on the weight load is confirmed. Therefore, if those are included in the design of the handover movement by a humanoid robot (deliverer), it is possible that people (receiver) will be able to estimate the weight load so that the package is received safely and certainly.

3 Design of Movement Depending on Weight Load

3.1 Design parameter

Four items listed below are chosen as the design parameter from the six noted points in Section 2.1. These items have comparatively small difference and small variations among individuals, and many subjects mentioned them as the attention point in the verification experiment [2] to check whether people can read out the difference in weight load from the variance of movement. The movement with a different weight load is generated varying the following items: (1) *Distance between the target point and the transferred point (in front-back direction)*, (2) *Distance between the highest point and the transferred point (in vertical direction)*, (3) *Elbow rotation angle*, and (4) *Waist joint angle*.

3.2 Design principle

The movement for an arbitrary weight load is generated processing the standard data at $0\ kg$ of weight load. The fitted curve of the parameter variation depending on the weight load is computed from the analysis result mentioned above.All the necessary procedure is as follows: (1) Sort out the movement data which follows totally the tendency of all movement data measured. (2) Compute the average movement data from the movement data sorted out. (3) Derive the first-order or second-order fitted curve of the parameter variation depending on the weight load. (4) Assume that the parameter increases or decreases monotonically depending on the weight load and it remains constant after the peak of the second-order approximated curve. (5) Process the standard data at 0 kg of weight load based on the fitted curve in each parameter so that the movement at the target weight load is created.

3.3 Movement generation with varying design parameters

The varying of parameters is shown concretely as follows:

(1) *Distance between target point and transferred point (in front-back direction):* The front-back position (x-direction) of the transferred point is processed while keeping the front-back distance to the target point from the waist joint. From the movement data sorted out, shown in the left of Fig. (2), the increase a_x at the transferred point depending on the weight load w is expressed in the following equation:

$$a_x = -0.0056w^2 + 0.3103w \tag{1}$$

The front-back hand position x' processed for each instant of time during an operation is generated with expanding according to the transferred position:

$$x'_i = x_i + \frac{x_i - x_0}{x_{fin} - x_0} a_x \tag{2}$$

where x_0: fore-back hand position at the beginning of the movement, x_{fin}: fore-back hand position at the end of the movement, x_i: fore-back hand position for each instant of time before processing, and x'_i: fore-back hand position after processing.

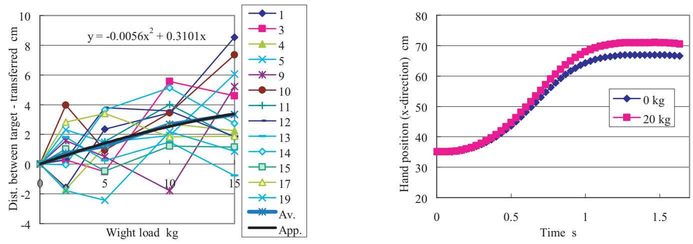


Figure 2: Distance between target point and transferred point (x-direction) from sorted data (left) and processed hand position (x-direction) during operation (right)

The processing result of the hand position (x-direction) at 0 and 20 kg of weight load is shown in the right of Fig. (2). (2) *Distance between highest point and transferred point (in vertical direction):* The vertical position (z-direction) of the transferred point is processed while keeping the vertical distance to the highest point from the waist joint. From the movement data sorted out, shown in left of Fig. (3), the increase a_z at the transferred point depending on the weight load w is expressed in the following equation:

$$a_z = -0.0509w^2 + 1.2736w \tag{3}$$

The vertical hand position z' processed for each instant of time during an operation is generated with expanding according to the transferred position:

$$z'_i = z_i + \frac{z_i - z_{max}}{z_{max} - z_{fin}} a_z \tag{4}$$

where z_{max}: vertical hand position at the highest, z_{fin}: vertical hand position at the transferred, z_i: vertical hand position for each instant of time before processing, and z'_i: vertical hand position for each instant of time after processing. The vertical hand position is processed between the highest and the transferred based on the analysis result in Section 2.1. The processing result of the hand position (z-direction) at 0 and 20 kg of weight load is shown in the right of Fig. (3). The hand trajectory in sagittal plane combining the processing result in front-back direction, Fig. (2), and vertical direction, Fig. (3), is shown in Fig. (4). (3) *Elbow rotation angle:* The feature is looked on the average value during an operation; therefore, it is processed so that the average may change. From the movement data sorted out, shown in the left of Fig. (5), the increase a_e depending on the weight load w is expressed in the following equation:

$$a_e = 0.9915w \tag{5}$$

The elbow rotation angle e' processed for each instant time during an operation is generated simply with adding the increase:

$$e' = e + a_e \tag{6}$$

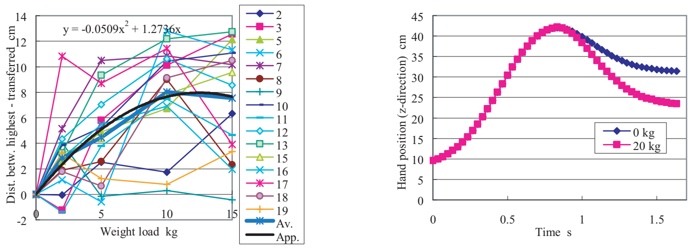


Figure 3: Distance between highest point and transferred point (z-direction) from sorted data (left) and processed hand position (z-direction) during operation (right)

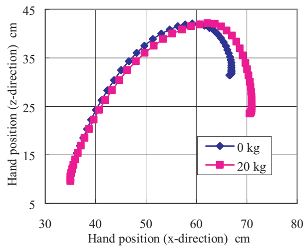


Figure 4: Processed hand position (sagittal plane) during operation

where e: elbow rotation angle for each instant of time before processing and e': elbow rotation angle after processing. The processing result of the elbow rotation angle at 0 and 20 kg of weight load is shown in the right of Fig. (5). (4) *Waist joint angle:* The feature is looked on the max-min difference during an operation; therefore, it is processed so that the difference may change. From the movement data sorted out, shown in the left of Fig. (6), the variation a_w depending on the weight load w is expressed in the following equation:

$$a_w = -0.04w^2 + 1.0631w \tag{7}$$

The waist joint angle w'_a processed for each instant time during an operation is set as follow:

$$w'_a = \frac{r - a_w}{r} w_a \tag{8}$$

where r: max-min difference before processing, w_a: waist joint angle for each instant of time before processing, and w'_a: waist joint angle after processing. The processing result of the waist joint angle at 0 and 20 kg of weight load is shown in the right of Fig. (6).

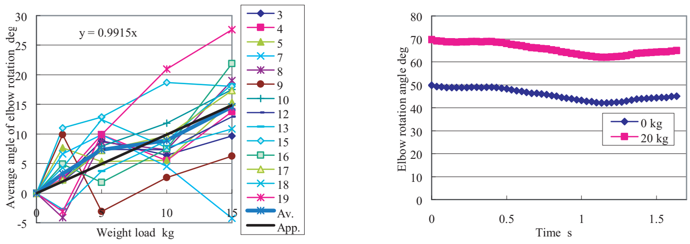


Figure 5: Elbow rotation angle from sorted data (left) and processed angle (right)

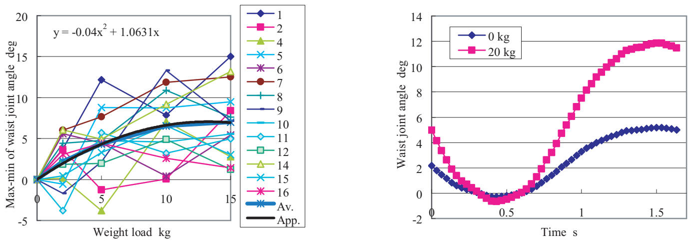


Figure 6: Waist joint angle from sorted data (left) and processed angle(right)

4 Evaluation Experiment

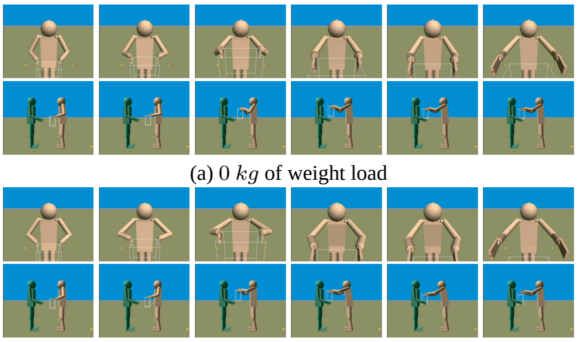
Whether people can read out the weight load from the variance of robot movement using the movement data generated by the technique explained in Section 3 is evaluated.

4.1 Creation of animation

The processing order of parameters is made into the elbow rotation angle, the waist joint angle, the distance between target point and transferred point (in front-back direction), and the distance between highest point and transferred point (in vertical direction). This is because the elbow rotation angle is independent of other parameters while the waist joint angle affects the hand position. The movement data at 0, 2, 5, 12, and 20 kg of weight load is generated for the evaluation experiment including heavier weight at which the human movement has not been measured. Two kinds of animation are prepared at each weight load – the front view (receiver's viewpoint) and the side view (third person's viewpoint), as shown in Fig. (7).

4.2 Experimental procedure

The experimental procedure is as follows: (1) A subject lifts up the package (cardboard box) at 10 kg of weight load with his both hands, and checks the weight. (2) Answer Q1 (How much weight is each package you think?) after he watches the animation at five kinds of weight load only once for each, and reply to Q2 (Which part in the



(a) 0 kg of weight load

(b) 20 kg of weight load

Figure 7: Animation (image in every 0.3 s)

animation do you pay attention to estimate the weight?). (3) Answer Q3 (How much weight is each package you think?) after he watches the animation at five kinds of weight load until he is convinced, and reply to Q4 (Which part in the animation do you pay attention to estimate the weight?). Seventeen male students in their early twenties reply to the questionnaire. The procedure is applied at the front view (receiver's viewpoint) and the side view (third person's viewpoint) in this order. The order of the animation at five kinds of weight load is made random for each subject.

4.3 Experimental results and discussion

(1) *Weight load estimation at first sight (Q1):* The difference between the estimated and the actual is large and highly variable both at the front view and the side view. It seems difficult to estimate the exact weight. The tendency of the average of the estimated weight load is in agreement with the actual weight load at the front view, although it doesn't show a significant difference among the data of the estimated weight load for each actual weight load, and it does not apply to the data at the side view. The variance of the elbow rotation angle depending on the weight load is obvious at the front view, however, it is invisible at the side view. Moreover, the variance of the waist joint angle depending on the weight load is relatively small and unclear even at the side view.

(2) *Weight load estimation after contemplation (Q3):* Both the variation and the tendency are improved in comparison with the estimation at first sight. When we consider the two groups – a light weight group (0, 2, and 5 kg) and a heavy weight group (12 and 20 kg), it is significantly different between the groups at the 0.01 level of significance. The percentage of subjects with correct answers whose order of the weight load estimated agrees with the order of two groups, regardless of the order in the groups, shows that about 30 $\%$ of subjects at first sight and more than 50 $\%$ of subjects after deep consideration have classified into two groups of the heavy load and the light load correctly, while the expected value is 10 $\%$. Therefore, a receiver will be able to read out the tendency (heavy or light) of the weight load from the movement to some extent.

(3) *Attention point (Q2 and Q4):* Many subjects point out the elbow rotation angle

and the waist joint angle both at the front view and the side view. Especially at the front view, a majority of subjects mentions the elbow rotation angle. The fact that many subjects pay their attention to the design parameter used to generate robot movement shows the validity of our design principle. Two subjects mention the height of the transferred point at side view, while nobody shows at front view. In the case of side view as a third person, it is easy to figure out the whole body movement of the deliverer and the locus and final position of the package. On the other hand in the case of front view as a receiver, the viewing angle is limited and the distance to the deliverer is short so that the range to observe the deliverer is narrow and the amount of information decrease. Moreover, there are several subjects who mention the not-varied part – the movement speed, the highest point, and the lower body movement – which might be pointed out as they usually pay their attention on the handover movement. Therefore, we have to study further on the parameters to design more natural movement in future.

5 Conclusions and Future Works

This paper presented the study results on the handover movement informing a receiver of the weight load as an example of the informative motion for the human-synergetic robot. To design and generate the movement depending on the weight load, the human movement was measured and analyzed, and four items were selected as the parameter to vary – the distance between target point and transferred point (in front-back direction), the distance between highest point and transferred point (in vertical direction), the elbow rotation angle, and the waist joint angle. The fitted curve of the parameter variation depending on the weigh load was obtained from the tendency of the subjects' movement data. The movement data for an arbitrary weight load was generated processing the standard data at $0\ kg$ of weight load so that each parameter follows the fitted curve. From the questionnaire survey, although it was difficult for a receiver to estimate the exact weight load, he might distinguish the heavy weight load from the light weight load so that the package would be received safely and certainly.

The measurement and analysis of human movement and the verification experiment were performed making male students in their early twenties subjects in this paper. Therefore, it is necessary to verify whether the same result might be obtained on various subjects by increasing the number of data. Moreover, the influence of other factors to affect the weight load estimation, such as the size of the package and the shape of the robot, should be studied.

References

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