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HANDING-OVER BETWEEN HUMAN AND SELF-MOVING TRAY

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Abstract: We aim for realizing a robotic system that hands over necessary objects to a user as soon as he/she attempts to reach out for it. In this study, we adopt self-moving trays as robots. In order to hand the objects to the user, the system has to predict the user's hand movements and adapt to them. In this paper, we propose a method to predict durations and final positions of reaching movements of the user's hand. We apply the minimum jerk model to the prediction and estimate parameters of the model by using Levenberg-Marquardt method. A description of the experimental results demonstrates the usefulness of the method proposed here.

Keywords: handing-over, attentive workbench (AWB), self-moving tray, the minimum jerk model, human-robot interaction.

1. INTRODUCTION

Over the past decade, several studies have been made on intelligent robotic systems that support our everyday life at home or in an office environment (e.g. [1-3]).

In our daily life, people typically spend a significant amount of time at their desks, doing computer work, reading and writing documents, letters, and books, eating lunch, and assembling objects.

Although people use many objects at their desks, it is impossible for them to keep all objects on hand due to limitations of their working space. Therefore, people have to put these objects out of the way and pick out the objects when they need them. People are often interrupted by such nonessential tasks.

In order to support people who work at their desks, in this study, we propose a system that hands necessary objects away to a worker.

Handing-over is one of the most fundamental tasks in human-robot interaction. Several studies focus on handing-over between a human and a robot.

Kajikawa et al. analyzed the motion of handing-over between two persons, and they proposed the method for motion planning of a manipulator based on an artificial potential field [4].

Agah and Tanie presented the method for handing-over between human and a mobile manipulator based on the contention control architecture [5].

In these studies, a manipulator was used as a "robot." When a worker needs to help, quickness is required.

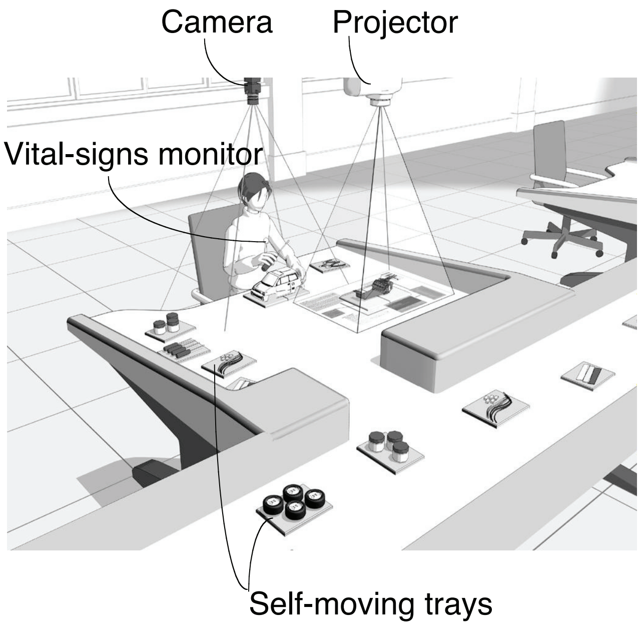

Fig. 1 Schematic view of Attentive Workbench (AWB)

However, it is quite dangerous for the worker that a manipulator moves quickly around the worker. Moreover, many objects are used at a desk, however a manipulator can grasp only one object at a time. Therefore, a manipulator cannot be applied to supporting individuals who work at desks.

To support deskwork, the authors have used self-moving trays as robots in "Attentive Workbench (AWB, Fig. 1) [6]."

AWB is intended to support human from both informational and physical viewpoints. The system uses a camera to recognize shapes and motions of user's hands and fingers. And vital signs monitors attached to a user observe his heart rate and respiration. Based on these acquired information, the system projects some appropriate information for carrying out tasks onto a desktop with a projector. Furthermore, self-moving trays, which run on linear motors, deliver necessary objects and clear unnecessary objects.

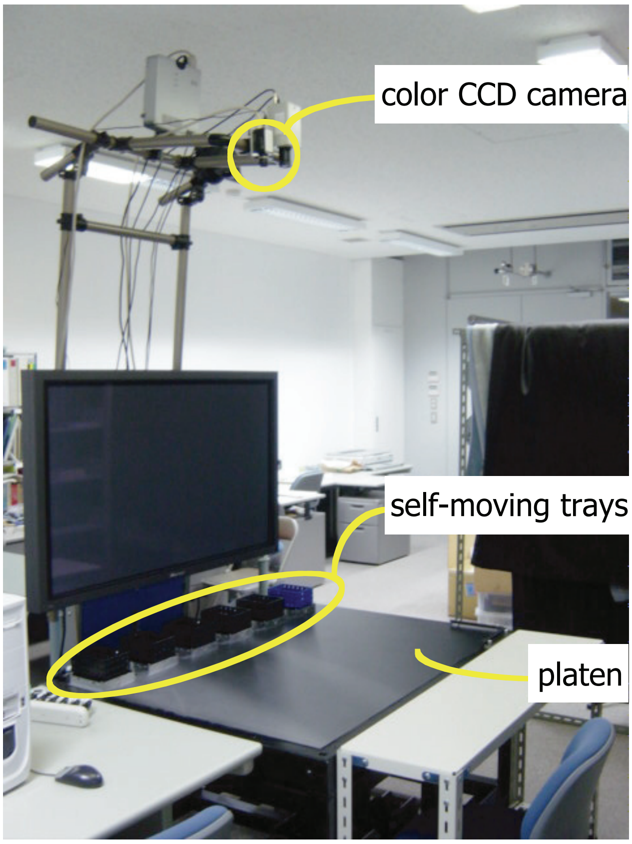

Fig. 2 Overview of the implemented self-moving tray system

In [7], we assumed that when a worker wants to be handed over an object on a self-moving tray, he/she expresses his/her intention by pointing a finger at the object.

Then the self-moving tray carries the object to the worker. It is true that pointing gestures are very intuitive, but it is an explicit way to instruct the system.

In this study, we aim for realizing a human supporting system that does not require any explicit indication.

In section 2, we outline a self-moving tray system used in this study. The approach of handing-over between a human and a self-moving tray is proposed in section 3. In section 4, the experiments for verifying the approach are described. In section 5, we conclude the paper and refer to future research.

2. SELF-MOVING TRAY SYSTEM

We introduce self-moving trays driven by a Sawyer-type 2-DOF stepping motor, which is known to have high speed, high positioning accuracy, and high thrust [8].

Fig. 2 shows the implemented self-moving tray system. The motors move on a platen, which is an iron plate having waffled grooves filled with insulating plastic. The motors are floated by compressed air lifts about 12 μm above the platen surface. Each tray is 13.0 cm × 13.5 cm rectangle shape, with a speed up to about 90.0 cm/s for each axis. Acceleration is up to 750 cm/s^2, a positioning accuracy is 30μm, and a thrust is 45 N at maximum.

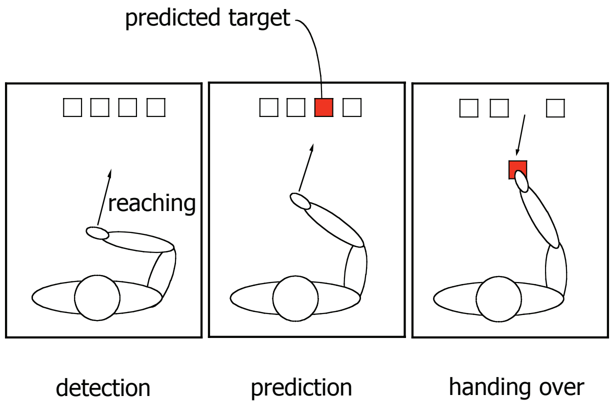

Fig. 3 Concept image of the proposed system

3. HANDING-OVER BETWEEN HUMAN AND SELF-MOVING TRAY

In this study, we propose a system that hands over between necessary objects to a user as soon as he/she attempts to reach out for it (Fig. 3). That is, a reaching movement of a human is not only for catching necessary objects but for conveying his/her intention to the system.

In order to realize such system, the followings are required:

- **Detection of a reaching movement**: It is necessary to determine whether a user doing some tasks or reaching out for an object.
- **Prediction of the target object**: The system has to predict the target object among various objects in real time.
- **Handing over the object**: It is required to hand the necessary object to the user.

The authors discussed the first two of them in [9]. In this paper, we discuss mainly the third problem.

3.1. Reaching movement of a human arm

The studies of mathematical models for human arm trajectory planning have attracted considerable attention, such as the minimum jerk [10], the minimum torque change [11], the minimum variance [12], etc.

These models dealt with PTP (Point To Point) movement of a human arm. That is, these models assumed that target objects are stationary.

On the other hand, reaching for moving objects has been studied in the cognitive and robotics fields.

The research by von Hofsten et al. showed that even infants' reaching movements are predictive when the object moves linearly [13].

Kajikawa et al. presented that humans decide the catch position beforehand by the prediction of the object movement and generate point-to-point movement like programmed movement when they do not consider the shock of contact [14]. When they need to consider the shock of contact, they first approach the object with a straight trajectory, then turn their hand motion to track the object,

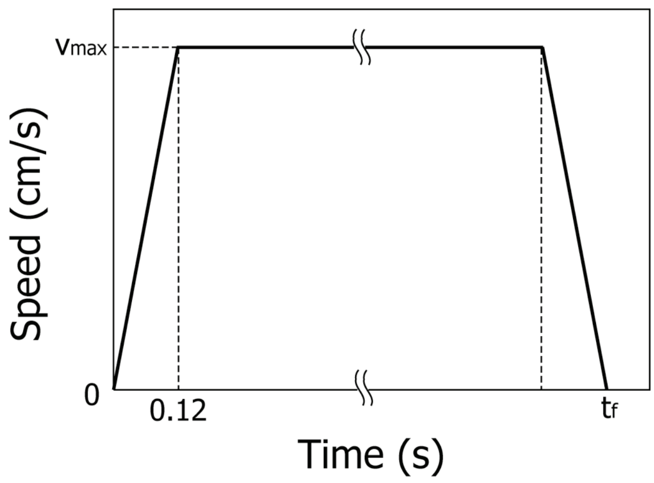

Fig. 4 Velocity profile of the self-moving tray (vmax: maximum velocity, tf: duration of the movement)

and finally accelerate the hand to reduce the relative velocity to the object close to zero.

Daum et al. compared human hand movements in two conditions, such as reaching for linearly moving object (predictable) and for non-linearly moving object (unpredictable) [15]. And they described that the strategy taken by human changes as the way of target movement.

From these studies, it can be said that if the movement of a self-moving tray is predictable for a worker, he/she reaching movements become predictive.

We assume that the reaching movement for moving target can be equated with the movement for stationary target after learning the movement characteristic of the tray sufficiently.

Using some measurement devices attached to a worker is viewed as a way to precisely measure the hand movements.

It is however unreasonable for a worker to be attached such devices while he/she is doing actual deskwork.

In this study, therefore, we use a color CCD camera attached to the ceiling to measure the hand movements. In addition, here, we define the hand movement as the movement of the center of worker's hand.

The RGB video data is first converted to hue, saturation, and value (HSV) space. Then the hue and saturation values are thresholded to acquire binarized hand images.

After that, we apply a morphological erosion operator to the obtained hand region until it becomes smaller than a predetermined threshold value, and the center of user's hand is given as the resulting regions' center of mass. This makes the hand's center insensitive to changes of the shape of the hand image [16].

3.2. Motion of a self-moving tray

As evidenced by the discussion in section 3.1, the motion of a self-moving tray should be predictable for human.

In this study, we simply define the motion of the tray as follows:

- The tray moves linearly from the initial point to the goal point.
- The tray first accelerates at constant rate, then moves at the constant velocity, and finally decelerates at constant rate (Fig. 4).

When the tray takes an oblique direction as shown in Fig. 5, the maximum speed of the longer direction ($|v_{\mathrm{long}}|$) is 90.0 cm/s and that of the shorter direction ($|v_{\mathrm{short}}|$) is $90.0\tan\theta$ cm/s. Therefore, the maximum speed of the tray ($|v|$) is $90.0/\cos\theta$ cm/s.

3.3. Handing-over

In order to hand necessary objects to a worker, the tray system has to determine the position and the timing at which the handing-over task will be performed. Moreover, the system has to carry the objects to the position at the timing

Based on the assumption stated in section 3.1, we consider that some mathematical models for human PTP motion can be applied to reaching movements here.

In this study, we adopt the minimum jerk model [10] for predicting human reaching movements. Assuming the minimum jerk model, human reaching movements minimize the following equation:

$$C_J = \frac{1}{2}\int_0^{t_f}\left\{\left(\frac{d^3x}{dt^3}\right)^2 + \left(\frac{d^3y}{dt^3}\right)^2\right\}dt \qquad (1)$$

Assuming the movement to start and end with zero velocity and acceleration, the following equations for hand trajectory are obtained:

$$x(t) = x_0 + (x_0 - x_f)(15\tau^4 - 6\tau^5 - 10\tau^3) \qquad (2)$$

$$y(t) = y_0 + (y_0 - y_f)(15\tau^4 - 6\tau^5 - 10\tau^3) \qquad (3)$$

where $\tau = t/t_f$, (x_0, y_0) is the initial hand position at $t = 0$, and (x_f, y_f) is the final hand position at $t = t_f$.

In order to determine where and when the tray carries the objects, the system estimates the parameters of the model from the sequence of the hand's positions. For estimating the parameters, we use Levenberg-Marquardt method [17] for non-linear least squares.

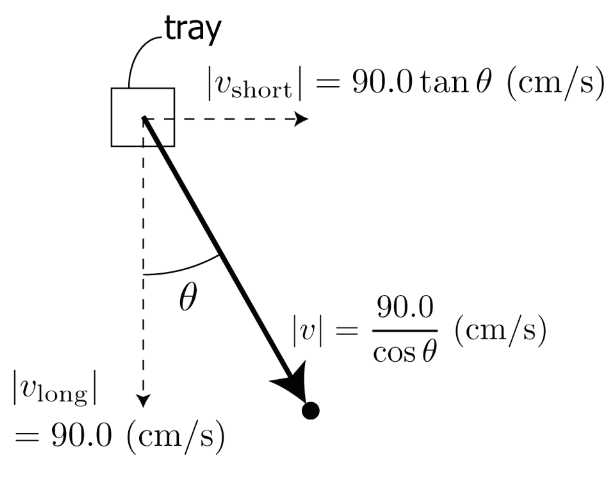

Fig. 5 Velocity of the self-moving tray during taking an oblique direction

To put it more concretely, the parameters, t_f, x_f, and y_f, are found by minimizing the following equation:

$$F(t_f, x_f, y_f) \equiv \sum_{i=1}^{N}\left[\left\{\frac{x_i - x(t_i;t_f,x_f)}{\sigma_i}\right\}^2 + \left\{\frac{y_i - y(t_i;t_f,y_f)}{\sigma_i}\right\}^2\right] \quad (4)$$

where t_f is the duration of the reaching movement. The standard deviation (σ_i) is assumed to be in inverse proportion to the speed of hand (v_i).

When using Levenberg-Marquardt method, obtained solutions depend on the initial parameters. Therefore, it is very important to assign initial values to the parameters appropriately.

In this study, we determine the initial values of the parameters (x_f^0, y_f^0) as stated below. Here, we assume that the travel distance of the hand is a half of the length of human arm (l_{arm}) and the hand trajectory is straight lines through its initial position as follows:

$$y = m(x - x_0) + y_0 \quad (5)$$

Then m, the slope of the line, is estimated with the linear least squares method as follows:

$$\sum_{i=1}^{n}\left[y_i - \{m(x_i - x_0) + y_0\}\right]^2 \to \min \quad (6)$$

Thus, the initial values of the parameters can be determined by following equations:

$$\begin{cases} x_f^0 = x_0 + \dfrac{l_{arm}}{2}\cos\theta \\ y_f^0 = y_0 + \dfrac{l_{arm}}{2}\sin\theta \end{cases} \quad (7)$$

where $\theta = \tan^{-1}(m)$.

4. EXPERIMENTS

To verify the proposed method, we examined the experiments as described below.

4.1. Experimental setup

An experimental subject is sitting at a desk and he reaches his arm to grasp a target object on the center of the tray. The target object is a right circular cylinder with a radius of 2.6 cm and a height of 10.4 cm.

The initial position of the hand is about the origin of the coordinate and the initial positions of the targets are shown in Fig. 6.

What has to be noticed is that the target positions cannot be reached unless the tray moves. In the following experiments, the tray moves to the point midway between the initial positions of the tray and the hand.

That is, in the following experiments, the tray predicts final hand positions, but the prediction is not used for the motion of the tray. We only evaluate the error between the final hand positions and predicted final hand positions.

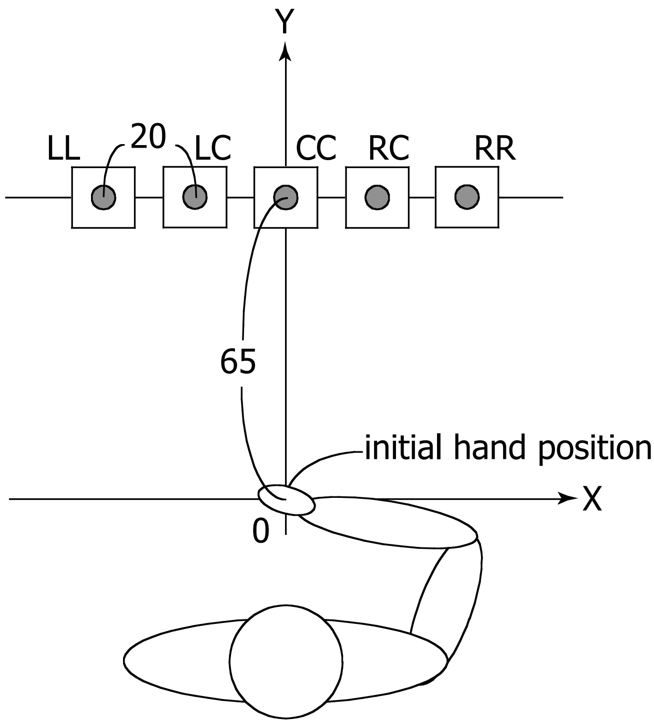

Fig. 6 Experimental setting

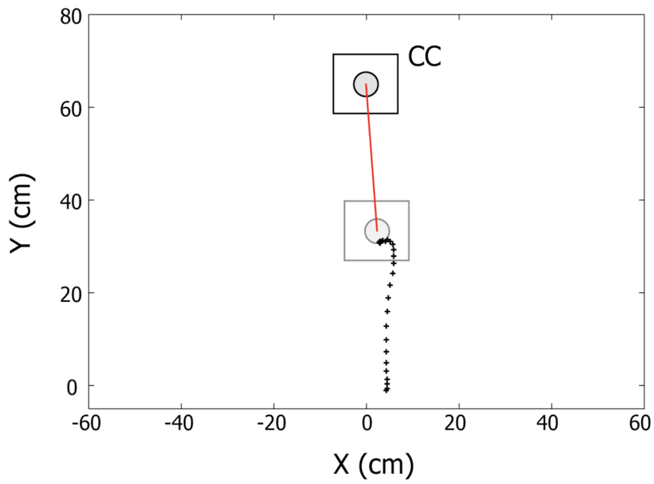

Fig. 7 Observed trajectories of the hand and the tray at the fist trial (the initial position of the tray is CC)

The experimental subject is right-handed and he used his dominant hand in the following experiments. The subject repeats 10 times to each target position (LL, LC, CC, RC, and RR).

A color CCD camera (VCC-8350CL, CIS) measures the subject's hand. For image processing, we used a PC (Intel Xeon, Dual 3.0GHz) with an image processing board (GINGA digital CL-2, Linx) and an image processing software (HALCON 7.0, MVTec). And frame rate is 30.0 fps.

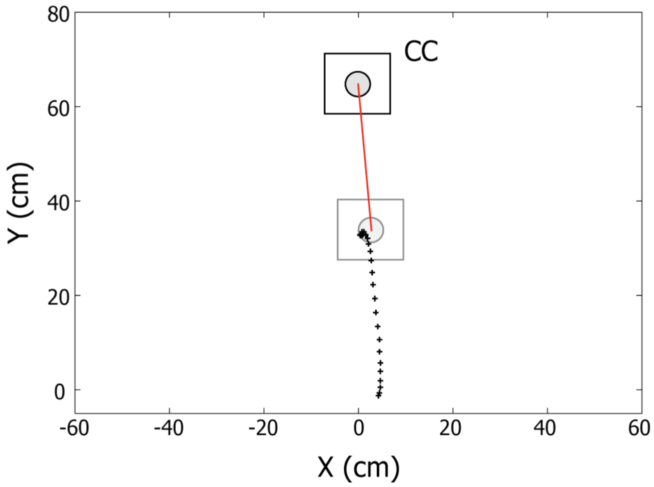

Fig. 8 Observed trajectories of the hand and the tray at the 10th trial (the initial position of the tray is CC)

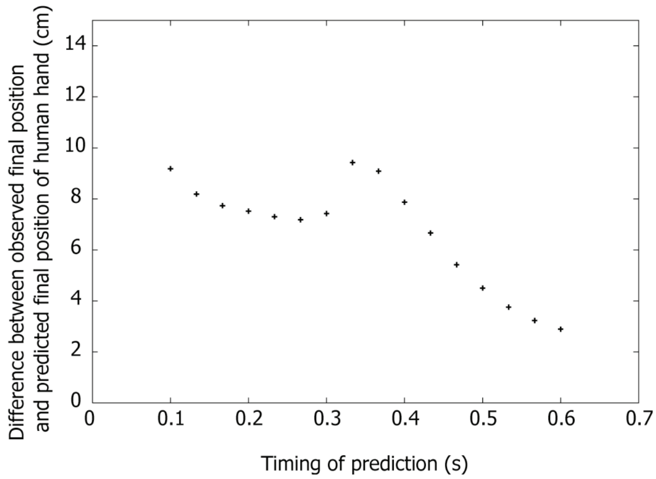

Fig. 10 Relation of the difference between observed final position and predicted final position of human hand to the timing of prediction

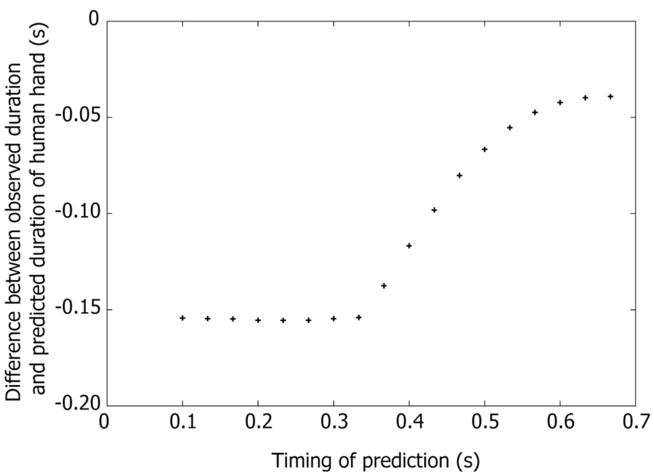

Fig. 9 Relation of the difference between observed duration and predicted duration of human hand to the timing of prediction

4.2. Experimental results

An example of the observed trajectories of the hand reaching movements at the first trial to the target CC is shown in Fig. 7.

As shown in Fig. 7, overshoot was observed at the end of the reaching movement at the first trial. The overshoot was due to adjustment of the hand position to the position of the target.

On the other hand, at the 10th trial, overshoot was not observed as shown in Fig. 8.

In this case, the trajectory of the hand is approximately straight. For the other targets, similar trajectories were observed.

The results indicated that the experimental subject learned the motion characteristic of the self-moving tray through experiments and he adapted his hand movements to the movements of the tray.

Fig. 9 shows the relation of the error between observed duration and predicted duration of human hand movements to the timing of prediction.

Here, the duration of the movements of human hand is defined as time period from the starting time of the movement to the time when the y-value of the hand is maximized or when the speed of the hand is less than 10 cm/s, whichever comes first.

The prediction accuracy of the duration of human hand movements increased as the timing of prediction was delayed.

Fig. 10 shows the relation of the error between observed final position and predicted final position of human reaching movement to the timing of prediction. Although a peak could be observed around 0.33 s, in general, the prediction accuracy of the final position of human hand movements also increased as the timing of prediction was delayed.

In the experiments, a self-moving tray moves in the negative y-direction by about 32.5 cm. As this is longer than the distance in the x-direction for any initial positions of the tray, based on the description in section 3.2, required time for the tray to move is about 0.48 s.

On the other hand, the average duration of the hand movements is 0.65 s.

In order for the tray to reach the position for handing-over by the time human hand stops at the position, therefore, the tray has to start within 0.17 s after the hand starts. That is, only 0.17 s can be spent for the prediction of the final position of the hand reaching movement.

Considering the size of the tray and that of the hand, if the position error is within 10 cm, people could absorb the error. As shown in Fig. 10, the proposed method meets the required precision regardless of the timing of prediction.

5. CONCLUSION

In this paper, we proposed a deskwork support system that hands necessary objects to a worker. To be concrete, we presented a method for predicting duration and final position of the reaching movement of the worker's hand. In our method, the minimum jerk model is applied and the parameters of the model are determined by using Levenberg-Marquardt method.

The usefulness of the proposed method was demonstrated through experiments described in section 4.

We have two challenges for the future. One is the integration with the method for target estimation [8]. As people use many objects in real deskwork environments, the system must have multiple trays. Therefore, the estimation of the target tray among multiple trays is essential.

Another challenge is the evaluation of the tray's motion from the viewpoint of the human-robot mutual adaptation system. In the proposed system, not only the trays but also the worker adapt own motion to another's motion. Thus, the learning process of human has to be considered.

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