# BASIC CONSIDERATION ON PRESHAPING FOR CAPTURING A ROTATIONAL OBJECT

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Abstract: Preshaping is an important issue for a robot hand to grasp a moving object successfully. Generally, a moving object in 3D space has rotational motion as well as translational one. This study discusses dynamic preshaping issue for such an object changing the posture momentarily. In this paper, we focus on determining the timing for grasping the object. We first show a strategy to extract candidates of timing for grasping. We also verify the proposed strategy by experiments using a high speed hand with the assistance of a high speed vision.

Keywords: preshaping, high speed capturing robot, rotational object

## 1. INTRODUCTION

When grasping an object by hand, human makes approach to the object with an appropriate preshape of finger, so that he (or she) can naturally make contact with it. Such preshaing issues are also important for a robot hand to grasp an object, especially either the robot hand or the object is moving quickly. There have been various works [1]–[11] concerning preshaping issues. Bard and Troccaz [1] have extracted the shape of object by vision and determined the hand preshape based on the information. Kang and Ikeuchi [2] have computed various points leading to a successful grasping with the help of vision, and found the finger tip level preshaping where each finger tip easily reaches the computed point. These works suppose that the object is stationary or moving slowly. Under such a quasi-static condition, so far, they have handled the issue for determining the preshape of robot hand.
On the other hand, with the increase of sensing speed, it is possible to chase the moving object by a high speed vision. For example, Namiki and others [9] have realized a dynamic catching of a sphere object by the combination of the 1ms-vision and a high speed robot hand. Higashimori and others [11] have discussed the design of robot hand suitable for capturing a moving object under the 100G acceleration. Under such a high acceleration, the preshaping issue is really important. Without an appropriate preshaping, it is impossible to successfully catch an object. These works, however, treat simple objects only, such as sphere or circle, as shown in Fig.1(a).
Now, suppose that a robot hand captures an object whose shape much differs from phase to phase, as shown in Fig.1(b). For such an object, we have to consider the orientation of object as well as its position. This paper discusses the preshaping issue for such an object. Especially, we are interested in the timing issue on how to determine the time appropriate for successfully catching the object, by supposing a high speed vision.
This paper is organized as follows: We show the problem formulation in chapter 2, and discuss a strategy in chapter 3 how to determine the position of hand by assuming that the object moves with constant translational and rotational velocities. We verify the idea through a couple of experiments in chapter 4. We give some discussions on the relationship between the rotational velocity of object and that of finger joint, in chapter 5, before concluding.

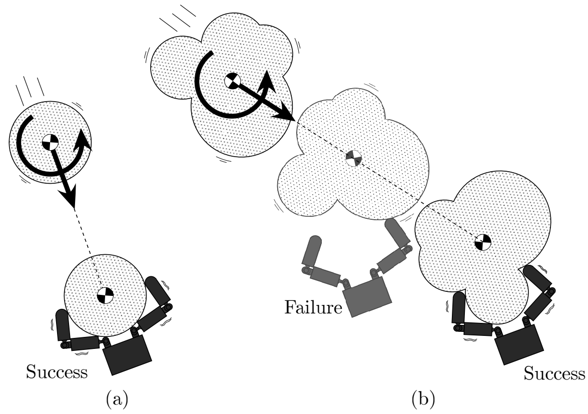


**Fig. 1** Capturing a rotational object

## 2. PROBLEM FORMULATION

Suppose the two-dimensional robot-object system as shown in Fig.2, where $\Sigma_R$, $\Sigma_g$, $\Sigma_h$, $\theta_g$, $\theta_h$, $\boldsymbol{p}_g$, and $\boldsymbol{p}_h$ denote the absolute coordinate system, the object coordinate system, the hand coordinate

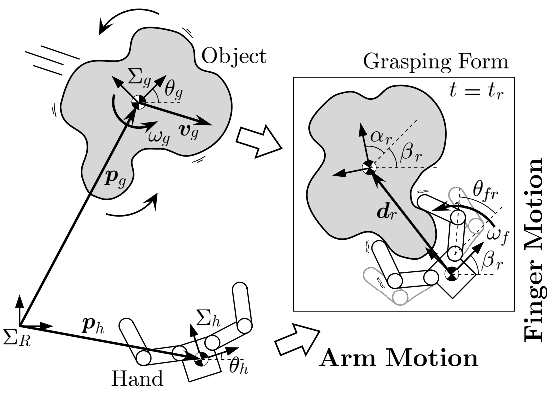


**Fig. 2** Coordinate system

system, rotational angle of object with respect to $\Sigma_R$, rotational angle of hand with respect to $\Sigma_R$, the position vector of object with respect to $\Sigma_R$, and the position vector of hand with respect to $\Sigma_R$, respectively. Let $\boldsymbol{v}_g$ and $\omega_g$ be the translational velocity and the rotational velocity of object, respectively. We suppose that $\boldsymbol{p}_g$, $\boldsymbol{p}_h$, $\theta_g$, $\theta_h$, $\boldsymbol{v}_g$, and $\omega_g$ are all known.

**Problem Formulation:** Determine the time $t = t_r$, so that the following conditions can be satisfied.

$$\begin{pmatrix} \boldsymbol{p}_h(t) \\ \theta_h(t) \end{pmatrix} = \begin{pmatrix} \boldsymbol{p}_g(t) \\ \theta_g(t) \end{pmatrix} - \begin{pmatrix} \boldsymbol{d}_r \\ \alpha_r \end{pmatrix} \quad (1)$$

$$\theta_h(t) = \beta_r \quad (2)$$

where $\boldsymbol{d}_r$, $\alpha_r$, and $\beta_r$ are the constants showing the relative position between the hand and the object at the goal, the relative orientation between them, and the absolute posture of hand, respectively.

This paper focuses on the timing issue but not on the finger shape at the goal. As for hand, we suppose that each finger has only one rotational degree of freedom at the base and both fingers start to rotate at $t = t_r - t_f$ with $\omega_f$, where

$$t_f = \frac{\theta_{fr} - \theta_f(0)}{\omega_f} \quad (3)$$

where $\theta_{fr}$ and $\theta_f(0)$ are the reference angle of finger and the initial angle, respectively.

## 3. STRATEGY TO DETERMINE TIME FOR GRASPING

In this chapter, supposing that the hand has two translational d.o.fs and one rotational d.o.f at its base, we discuss the issue for determining the time for capturing an object with rotating as well as

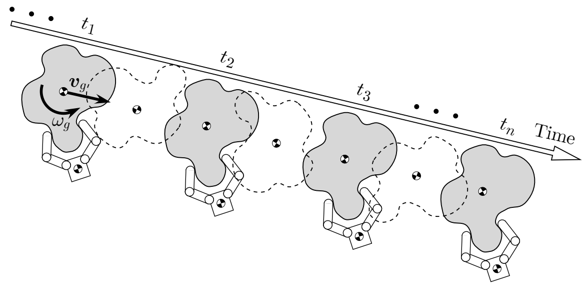


**Fig. 3** Timings for grasping a rotational object

translating motions. Since the object is assumed to move with constant velocity, we can express the position and the orientation with respect to time as follows:

$$\begin{pmatrix} \boldsymbol{p}_g(t) \\ \theta_g(t) \end{pmatrix} = t \begin{pmatrix} \boldsymbol{v}_g \\ \omega_g \end{pmatrix} + \begin{pmatrix} \boldsymbol{p}_g(0) \\ \theta_g(0) \end{pmatrix} \quad (4)$$

where $t$, $\boldsymbol{p}_g(0)$ and $\theta_g(0)$ are time, initial position and orientation, respectively. From eq.(1), (2), and (4), we can obtain candidates of time for capturing as follows:

$$t_n = \frac{\alpha_r + \beta_r - \theta_g(0)}{\omega_g} + \frac{2n\pi}{|\omega_g|} \quad (n = 0, 1, 2, \cdots) \quad (5)$$

where $n$ denotes non-negative integer. From eq.(5), we can see that a candidate time appears periodically, as shown in Fig.3. We now suppose that both translational and rotational speeds are constrained by their upper limitations, respectively, as follows:

$$\begin{pmatrix} \|\dot{\boldsymbol{p}}_h(t)\| \\ |\dot{\theta}_h(t)| \end{pmatrix} \leq \begin{pmatrix} V_h^{\max} \\ \Omega_h^{\max} \end{pmatrix} \quad (6)$$

where $V_h^{\max}$ and $\Omega_h^{\max}$ denote the maximum translational speed and rotational speed, respectively. Now, a natural question is how to choose an appropriate time among all candidates of time. Suppose that the hand is taking its capturing action for the selected time $t_n$, as shown in Fig.4, where $\boldsymbol{p}_h^r(t_n) = \boldsymbol{p}_g(t_n) - \boldsymbol{d}_r$ denotes the reference position of hand at time $t_n$. At the capturing point, the moving distance and the rotational angle of hand are given by $\|\boldsymbol{p}_h^r(t_n) - \boldsymbol{p}_h(0)\|$ and $|\beta_r - \theta_h(0)|$, respectively. The necessary condition for the hand to reach the goal position is given by

$$t_n \geq t_h(t_n) \quad (7)$$

$$t_n \geq \frac{|\beta_r - \theta_h(0)|}{\Omega_h^{\max}} \quad (8)$$

where

$$t_h(t_n) = \frac{\|\boldsymbol{p}_h^r(t_n) - \boldsymbol{p}_h(0)\|}{V_h^{\max}} \quad (9)$$

We further suppose the following constraint for hand, as shown in Fig.5, where $\boldsymbol{p}_h^{\min}$ and $\boldsymbol{p}_h^{\max}$ denote the minimum and the maximum movements

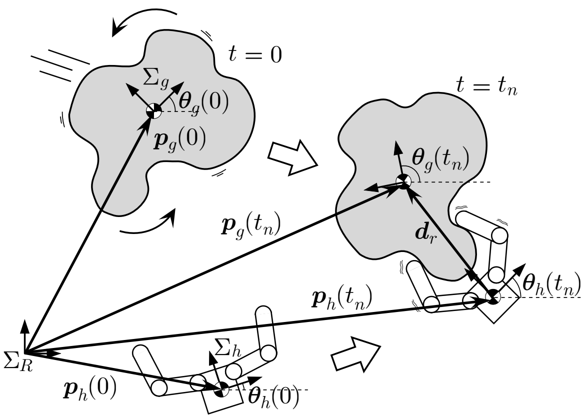


**Fig. 4** A time $t_n$ for grasping a rotational object

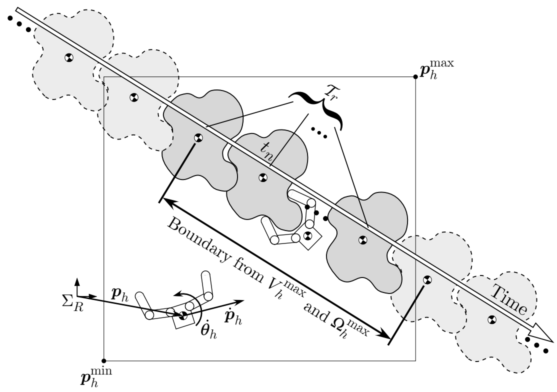


**Fig. 5** A set of candidate $\mathcal{T}_r$

of hand, respectively.

$$\boldsymbol{p}_h^{\min} \;\le\; \boldsymbol{p}_h(t) \;\le\; \boldsymbol{p}_h^{\max} \tag{10}$$

Accordingly, the goal position of hand receives the following constraint as well.

$$\boldsymbol{p}_h^{\min} \;\le\; \boldsymbol{p}_h^r(t) \;\le\; \boldsymbol{p}_h^{\max} \tag{11}$$

Based on the above consideration, we are allowed to choose the capturing time from the following assemble $\mathcal{T}_r$:

$$\mathcal{T}_r = \left\{ t_n \;\middle|\; \begin{array}{l} t_n = \frac{\alpha_r+\beta_r-\theta_g(0)}{\omega_g} + \frac{2n\pi}{|\omega_g|} \\ \qquad (n = 0, 1, 2, \cdots) \\ t_n \ge t_h(t_n) \\ t_h(t_n) = \frac{\|\boldsymbol{p}_h^r(t_n)-\boldsymbol{p}_h(0)\|}{V_h^{\max}} \\ t_n \ge \frac{|\beta_r-\theta_h(0)|}{\Omega_h^{\max}} \\ \boldsymbol{p}_h^{\min} \;\le\; \boldsymbol{p}_h^r(t_n) \;\le\; \boldsymbol{p}_h^{\max} \end{array} \right\} \tag{12}$$

Fig.5 shows the relationship between the constraint condition and the assemble $\mathcal{T}_r$. Generally, possible candidates for capturing time increase as either the translational velocity decreases or the rotational velocity increases.

On the other hand, we have to choose one time among candidates for real application. This need additional constraint, for example:

(a) The minimum (or maximum) time between sensing and grasping

$$t_r = t_n \;\middle|\; \begin{array}{l} \min\ \{t_n\}, t_n \subset \mathcal{T}_r \\ (\max) \end{array} \tag{13}$$

(b) The minimum (or maximum) distance of hand movement

$$t_r = t_n \;\middle|\; \begin{array}{l} \min\ \{\|\boldsymbol{p}_h^r(t_n) - \boldsymbol{p}_h(0)\|\}, t_n \subset \mathcal{T}_r \\ (\max) \end{array} \tag{14}$$

(c) The minimum (or maximum) waiting time at the capturing point

$$t_r = t_n \;\middle|\; \begin{array}{l} \min\ \{t_n - t_h(t_n)\}, t_n \subset \mathcal{T}_r \\ (\max) \end{array} \tag{15}$$

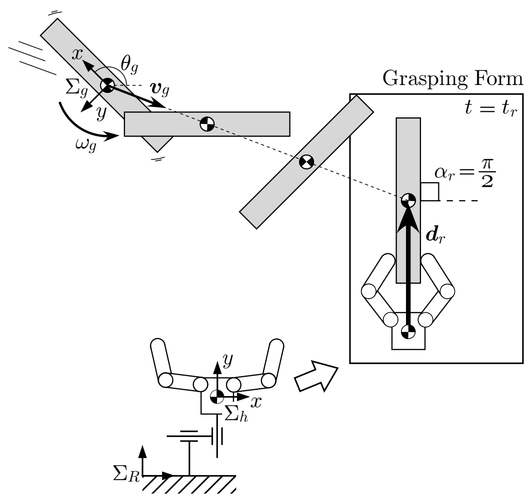


**Fig. 6** Capturing a stick-shaped object using a 2-DOF translational arm/hand

We would note that these additional constraints should be slightly modified based on the shape of object and the mechanism of arm. We would also note that the second term of eq.(5) may change according to how often the combination of graspable points appear during one rotation.

## 4. EXPERIMENTS

Fig.6 shows the experimental system where the base of hand can move in two d.o.f (the $x$ and $y$ directional motions), and a high speed vision is installed to detect the position and velocity of object.

### 4.1 *Capturing a stick-shaped object*

Suppose the arm/hand system as shown in Fig.6, where $\theta_h = 0$. Under this mechanical configuration, ineq.(6) and eq.(9) can be converted as follows:

$$\begin{pmatrix} |\dot{p}_{hx}(t)| \\ |\dot{p}_{hy}(t)| \end{pmatrix} \le \begin{pmatrix} V_{hx}^{\max} \\ V_{hy}^{\max} \end{pmatrix} \tag{16}$$

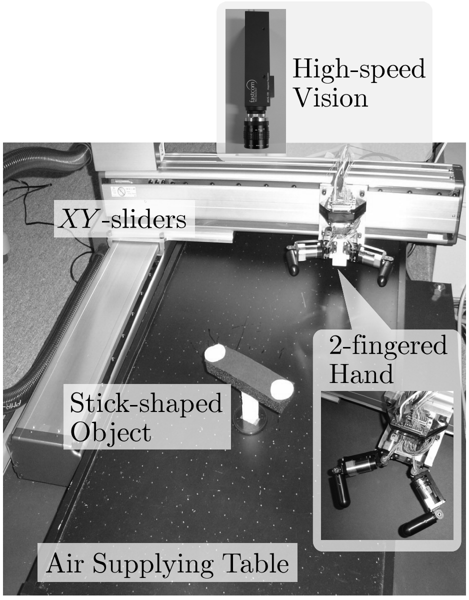


**Fig. 7** An overview of experimental system

$$t_h(t_n) = \max\left\{\frac{|p_{hx}(t_n)-p_{hx}(0)|}{V_{hx}^{\max}}, \frac{|p_{hy}(t_n)-p_{hy}(0)|}{V_{hy}^{\max}}\right\} \quad (17)$$

where the $x$ direction is chosen so that the direction may be coincided with the longitudinal direction of object. The goal position and posture of object are given as follows:

$$\begin{pmatrix} \boldsymbol{p}_h(t) \\ 0 \end{pmatrix} = \begin{pmatrix} \boldsymbol{p}_g(t) \\ \theta_g(t) \end{pmatrix} - \begin{pmatrix} \boldsymbol{d}_r \\ \frac{\pi}{2} \end{pmatrix} \quad (18)$$

where $\alpha_r = \pi/2$ and $\boldsymbol{d}_r = [0, d]^T$ are chosen, respectively. Furthermore, by supposing that both edges are allowed to be grasped for this particular object, eq.(5) can be replaced by the following.

$$t_n = \frac{\frac{\pi}{2} - \theta_g(0)}{\omega_g} + \frac{n\pi}{|\omega_g|} \quad (n = 0, 1, 2, \cdots) \quad (19)$$

## 4.2 Experimental system

Fig.7 shows the experimental system where a high speed vision (iMVS-155 FastCom Technology Co. [12]) is implemented in the height of 1[m] from the table and the air is regularly supplied from the surface of table so that we can reduce the friction between the object and the table. We intentionally attach two white markers to the object so that the vision system can recognize both position $\boldsymbol{p}_g(t)$ and orientation $\theta_g(t)$ of object. The base of hand is measured by the encoder equipped with the motor for driving the slider. The hand is constructed by two fingers [13] and can produce the maximum rotational speed with $\omega_f$=14 [rad/s]. The slider can move within 400[mm]$\times$400[mm] with the maximum speed of 1000[mm/s] in each axis.

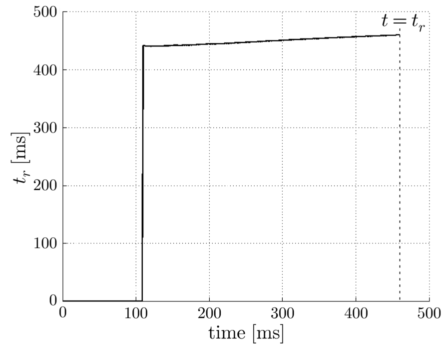


**Fig. 8** The estimated time for grasping with respect to time

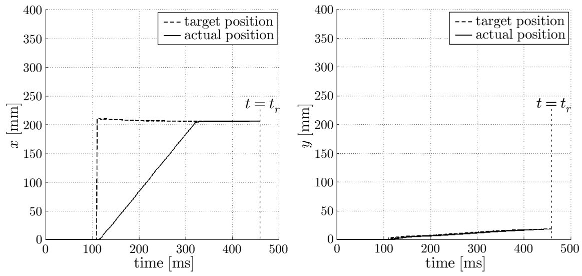


**Fig. 9** Target and actual positions of the hand

## 4.3 Experimental results

The first thing to do is to estimate $\boldsymbol{v}_g$, $\omega_g$, $\boldsymbol{p}_g(0)$, and $\theta_g(0)$, by utilizing the vision information. By continuously computing those parameters, we obtain the newest information on candidates for grasping, where we set that $\theta_f(0) = 0.44$[rad], $\theta_{fr} = 0.93$[rad], and $t_f = 35$[ms], respectively. Fig.8 shows an example of estimated time at grasping point where $|\dot{p}_{hx}| = 1000.0$[mm/s], $|\dot{p}_{hy}| = 1000.0$[mm/s], $\boldsymbol{p}_h^{\min} = [0.0, 0.0]^T$[mm], $\boldsymbol{p}_h^{\max} = [400.0, 400.0]^T$[mm], $\boldsymbol{p}_h(0) = [0.0, 0.0]^T$[mm], $\boldsymbol{d}_r = [0.0, 140.0]^T$[mm], $\boldsymbol{v}_g = [12.4, 618.9]^T$[mm/s], and $\omega_g = 17.47$[rad/s], respectively. We would note that the condition (14) is utilized for uniquely determining the time. From Fig.8, we can see that $t_r$ is converging after $t \geq 110$[ms], while it includes some small disturbance. Fig.9 shows the trajectory of the change of the goal position and actually tracked position, respectively. We can see that the $x$ and $y$ directional goal positions can be successfully estimated at $t = 350$[ms] for the $x$ direction and at $t = 110$[ms] for the $y$ direction, respectively. Fig.10 and Fig.11 show a series of motion during the grasping motion. At first, the hand keeps stationary at the waiting position, while the vision system continuously compute the goal position and orientation (Fig.10(a)). By taking the closing time of hand, the hand moves to the target position (Fig.10(b)-(d)) and waits until the object comes (Fig.10(e), Fig.11(a)). After the grasping

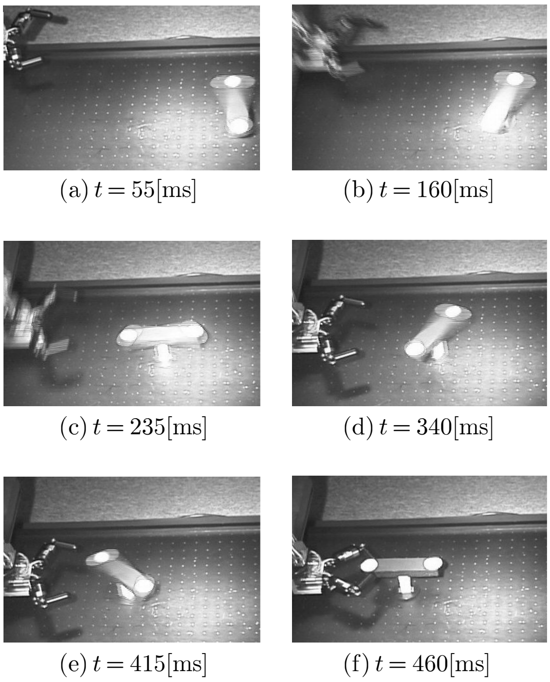


**Fig. 10** A series of photos during an arm motion for grasping a stick-shaped object

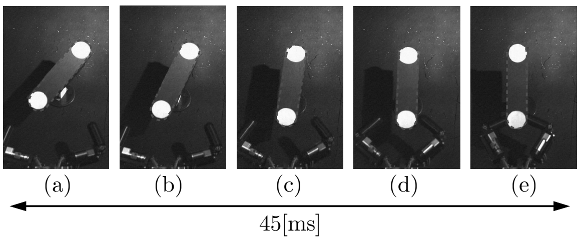


**Fig. 11** A series of photos during a finger motion for grasping a stick-shaped object

command is sent from the computer, both fingers start to close (Fig.11(b)-(d)). Finally, both finger can grasp the object successfully, as shown in Fig.10(f) and Fig.11(e).

## 5. DISCUSSION

In this chapter, we discuss the relationship between the angular velocity $\omega_f$ of finger and the velocity of object $(\boldsymbol{v}_g, \omega_g)$, We would once again confirm that each finger starts its closing motion at $t = t_r - t_f$ and completes the motion at $t = t_r$. For simplicity, we neglect the width of each finger and each finger is treated as just a stick without thickness. Also we suppose the case where there is no coupling between the arm motion and finger motion $(t_h(t_r) < t_r - t_f)$, as shown in Fig.12(a). By this assumption, we are released from the complicated motion when they make a collision and allowed to consider only the case where each finger completes its motion at the time $t = t_r$ without any collision with the target object. Fig.12 shows the geometrical relationship between the finger and the object just before making contact with each other, where $l_g$, $l_f$, $\phi_g$, and $\phi_f$ are the length between the center of gravity of the object and the tip of the object, the length between the base of finger and the finger tip, and the rotational angle of object between the intersecting point and the goal posture, and the rotational angle of finger between the intersecting point and the goal posture, respectively. In this case, the necessary condition for achieving the procedure explained in the previous chapter is given by

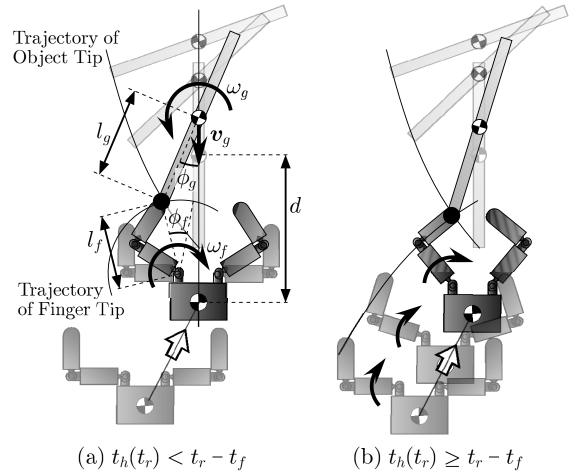


**Fig. 12** Geometrical consideration on capturing a stick-shaped object with rotational velocity

$$\frac{\omega_f}{\omega_g} > \frac{\phi_f}{\phi_g} \tag{20}$$

Ineq.(20) expresses the angular velocity $\omega_f$ necessary for achieving the target posture without being disturbed by the object with $(\boldsymbol{v}_g, \omega_g)$. Fig.13 shows the numerical simulation for the relationship between $\omega_f$ and $(\boldsymbol{v}_g, \omega_g)$, where $\omega_f$ should be inside of the shadowed area under the given data set, $\omega_f^{\max} = 30$[rad/s], $\boldsymbol{v}_g = [0, 0]^T$[mm/s] for the line(a), $\boldsymbol{v}_g = [0, -4200]^T$[mm/s] for the line(b), $\boldsymbol{v}_g = [2100, -3637]^T$[mm/s] for the line(c), $\omega_g^{\max} = 25$[rad/s], $l_g = 75$[mm], $l_f = 96$[mm], and $d = 140$[mm], respectively. From Fig.13, it can be seen that $\omega_f$ required the given $\omega_g$ on the line(b) increases very little from that of the line(a), while $\|\boldsymbol{v}_g\|$ is equal to that of the line(c). It means that we can pay attention to only the relationship between both rotational velocities if we can choose $\theta_h$ satisfying $v_{gx} = 0$. This is because we suppose that the base of hand can move with $\dot{\boldsymbol{p}}_h$ satisfying $t_h(t_r) < t_r - t_f$. In any case, it is important for us to increase the area so that we may have much success rate.

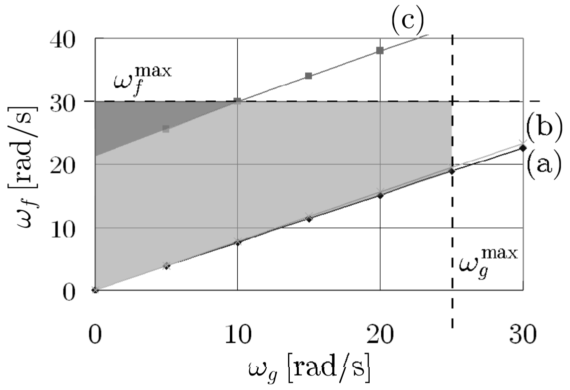


**Fig. 13** Relationship between velocities of finger and object

## 6. CONCLUSION

We discussed the issue on preshaping for capturing the object with rotational velocity as well as translational velocity. We particularly focused on the timing issue for planning the hand motion by linking with the object motion. The main results in this paper is as follows:

(1) Supposing a two dimensional hand, we showed a strategy for determining the time in grasping a moving object geometrically.
(2) The proposed strategy was confirmed experimentally with the assistance of a high speed vision system.
(3) We also considered the necessary condition required for the rotational velocity of finger, and showed the map in connection with the velocity of object.

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