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Dexterous Manipulation from Pinching to Power Grasping

-Effective strategy according to object dimensions and grasping position-

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Abstract

This paper discusses practical strategies for transition from a pinching to a power grasping, where a multi-fingered hand mounted on a robotic arm envelops a cylindrical object on a table. When the manipulation system grasps a cylindrical object like a pen on a desk, a complete enveloping is not impossible in the initial configuration. The system firstly pinches the object only with two or three fingers and then grasp it with fingers and a palm after regrasping. In this pinching-grasping transition maneuver, human unconsciously selects proper strategy according to some conditions including object dimensions and initial pinching positions. In this paper we therefore develop six possible strategies for this pinching-grasping transition and then investigate their performances for some objects with various dimensions and various grasping positions, using numerical simulations. Based on their results, effective strategies are implemented by using a hand-arm system.

1 Introduction

Various topics about manipulation system have been studied until now. They can be divided into three categories; multi-fingered hand system, manipulation arm, and hand-arm cooperation system. A multi-fingered robot hand has ability to achieve more various and dexterous handlings than a gripper-type robot hand[1]. For example, it can control slip motion[2], and it can regrasp an object while keeping grasping[3]. In addition, this multi-fingered hand with a palm can selectively achieve a power grasp which maximizes the load carrying capability and stability. However the grasping force is indeterminate. There are many researches about this matter[4]. On the other hand, a manipulation arm is used to carry and assemble a work in a factory, which has wider workspace than the fingered hand. The utility and capability of a multi-fingered hand can be enhanced like a human arm, by mounted on a manipulation arm. The system can arrange a relative orientation of a hand to a target object in the approaching phase and a hand posture in a regrasping phase. However the difficulty is appeared due to its redundancy. There are many possible solutions to satisfy a desired purpose, therefore some criterions are necessary to fix the solution. Kawarazaki proposed two methods to generate the grasp configuration for multi-fingered hand-arm robot in the presence of obstacles[5]. In these methods, heuristics are employed for planning. Kaneko proposed a control strategy for the pinching-grasping behavior [6]. The control strategy generates slip motion on the fingertip so that it could achieve a power grasp with a cylindrical object from the pinching phase without posture control of the hand system. This motion is quite fast but it is not generally effective in the viewpoint of energy because this slip motion is induced by much bigger grasping force than that for grasp. On the other hand, human can select the grasping strategy according to the conditions, such as object dimensions, object posture, weight, friction coefficient, and so on. Kleinmann categorized several pinching-grasping transition strategies either using a coordination of a hand and an arm or only manipulating the object with fingers and then made experiments using three-fingered manipulation system[7]. But there is no comparison with performances of their strategies.

In this paper, we focus on a pinching-grasping transition strategy of the hand-arm cooperation system which realizes a power grasp for a cylindrical object. The performance of the strategy is investigated when the dimensions of the object and grasping positions vary. In the following sections, six typical strategies to enclose a cylindrical object are developed and the performance of these strategies is investigated when the object dimensions and the initial grasping position vary in numerical simulations. Finally we make experiments based on three effective strategies with the hand-arm cooperation system.

2 Problem Setting

We consider the pinching-grasping transition maneuver in which the three-fingered hand mounted on the arm system pinches a cylindrical object on a table and encloses it through regrasping. The final state of the grasping object is arbitrary even if the hand encloses the object with three fingers and a palm and if the object is lifted from a table stably as shown in Fig. 1.

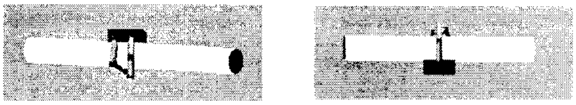

Figure 1: Desired final status(Power grasping)

The task sequence is as follows, At first the hand approaches a cylindrical object which is put on a table and then pinches it with two or three fingers. After that, the hand system with the object is lifted by an arm system so that the grasping object could partially or entirely disconnected from a table. In the next step, the hand regrasps the object for a power grasping and then lift the hand again until the object is entirely disconnected with a table.

The hand system has three finger, four joints and three DC motors on each finger so the first and the second joints from fingertip are coupled. The dimensions are illustrated in Fig.2. The force sensor with three axis is attached on the fingertip to measure a grasping force.

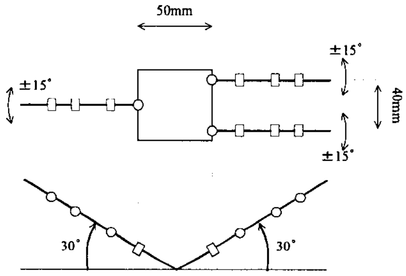

Figure 2: Hand mechanism

3 Pinching-Grasping Transition Strategy

We develop six pinching-grasping transition strategies for the target maneuver based on human behaviors. Some strategies take advantage of the environment to support the grasping object. The environment can not only help limitations of hand workspace and grasping force, but also work as the fourth finger to constrain the object.

3.1 Strategy 1

As a strategy 1, after a hand system grasps an object with two fingers as shown in Fig. 3, lift the hand system in order to make a space under the object for the third finger's insertion. The third finger then pulls up the object from the bottom until the object hits the palm. After that the two grasping fingers bends inside with slip for power grasping.

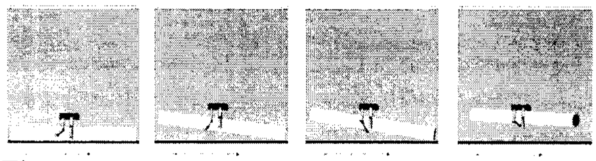

Figure 3: Sequence of strategy 1(The task flows from left to right.)

3.2 Strategy 2

In the strategy 2, a hand system grasps one side of an object with two fingers, and then rotates and lifts the hand system with the object in order for the other side of the object to make a contact with a table as shown in Fig.4. After that, the third finger encloses the object with the palm and then the two grasping fingers also enclose the object without slip motion, rotating the hand along with the object for a complete power grasping. In this case, the object is fixed by two fingers and a table as the third support at the initial state. It enable to lift the heavier object with the same grasping force than strategy 1. While the third finger encloses the object with palm, two fingers can release and then regrasp the object.

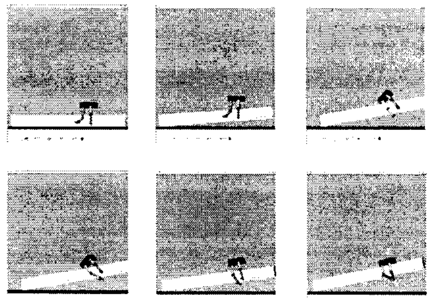

Figure 4: Sequence of strategy 2

3.3 Strategy 3

In the strategy 3, gravity is used for the transition. The arm rotate the hand system with the object 180 degree from pinching state after lifting of grasping object with two fingers. Enclose the object with the third finger and then two grasping finger release and regrasp the object. In this strategy, there is less grasping force required at power grasping phase because the object affected by gravity comes down to the palm automatically, while large grasping forces are required at an initial phase.

3.4 Strategy 4

Pinch the left side of an object with two fingers and then lift and rotate the hand system until the palm becomes parallel to the object axis. The other side of the object keeps a contact with a table during this rotation. After that, release the object so that it could drop to the palm and then enclose it with three fingers.

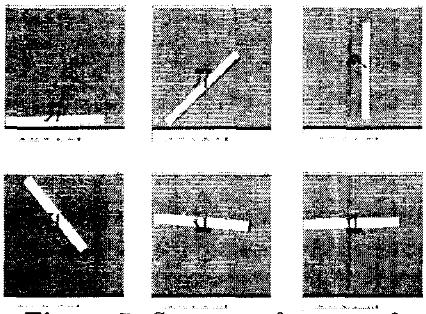

Figure 5: Sequence of strategy 3

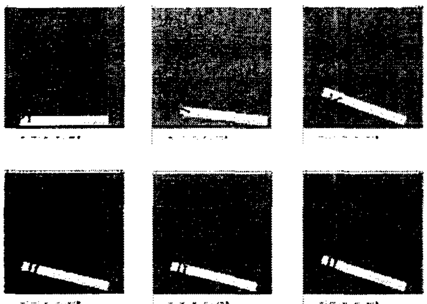

Figure 6: Sequence of strategy 4

3.5 Strategy 5

Pinch an object with two fingers and then lift and rotate hand system 180 degree around axis of the cylindrical object. In the same way the other side of the object keeps a contact with a table. Release the object so that it could drop to the palm and then enclose it with three fingers. This strategy can cover wide initial grasping positions than the strategy 4.

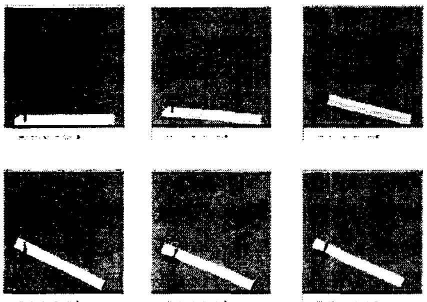

Figure 7: Sequence of strategy 5

3.6 Strategy 6

Grasp the object with three fingers and then lift and rotate it 180 degree around axis of the cylindrical object. In this case, the object is disconnected with a table. After that, release the object so that it could drop to the palm and then enclose it with three fingers. This strategy is simple, but it has an unstable phase when the object has no constrain.

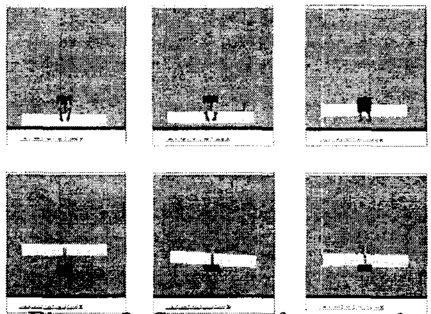

Figure 8: Sequence of strategy 6

4 Performance comparison of each strategy in numerical simulations

The utility of six strategies explained in the previous section will change according to the object dimensions and grasping point. We investigate the performance defined by eq.(1) of each strategy when the initial grasping point P_x in Fig.9 and the total object length $L(= l_l + l_R)$ changes.

$$J = \int_0^T \tau^T R \tau dt, \qquad (1)$$

where T is the end time of that maneuver, τ is actuator torque $\tau = [\tau_i : i = \{1, 9\}]^T$ and R is a unit matrix I_9.

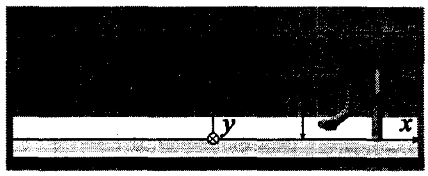

Figure 9: Wrist position P_x

Tables 1 shows the evaluation values when the each strategy is applied to various object dimensions. From numerical simulation results, we find that strategy 2 has better evaluations in any grasping position. The strategy 6 can be effective and applicable if it grasps at COG of the object. The strategy 4 becomes effective when it grasps at left end of a longer object.

Table 1: The evaluation value ($L = 400[mm], R = 20[mm], M = 0.1[kg]$ "×" means an impossible approach.)

[mm]	−160	−100	−50	$P_x = 0$	50	100	160
St1	×	0.045	1.172	0.268	0.271	0.352	0.462
St2	×	0.159	0.095	0.092	0.081	0.078	0.162
St3	×	×	×	0.836	3.698	5.568	7.78
St4	0.278	×	×	×	×	×	×
St5	0.477	0.718	0.563	0.307	0.397	0.612	0.536
St6	×	×	×	0.056	×	×	×

5 Expriments

The three-fingered hand system is mounted on a manipulator system with seven DOF. The control architecture is shown in Fig.10. Each system is controlled by its own controller and the task is synchronized via network. The diameter and length of the cylindrical object are 25[mm] and 360[mm], respectively. The weight is 0.1[kg]. When we indicate that the initial grasping point P_x and a lift distance P_z are -100[mm], 80[mm], the strategy 2 should be selected according to the numerical simulation. Figure 11 shows the pinching-grasping transition maneuver with strategy 2. Table 2 shows the evaluation value(eq.(1)) and task time of strategy 2, 4, and 6. The actuation torque is substituted with voltage of DC motor.

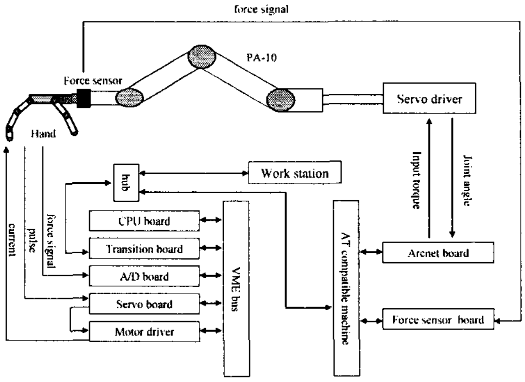

Figure 10: System architecture

Table 2: The evaluation value ($L = 360[mm], R = 25[mm], M = 0.1[kg]$)

	Grasping position P_x	Evaluation J	Time [s]
St2	-100	60.5	43
St4	-120	36.4	31
St6	0	35.6	33

6 Conclusions

In this paper, we developed six strategies for pinching-grasping transition maneuver based on human behaviors. These transitions are achieved by co-operating a hand and an arm system and then the grasping force is reduced by controlling the hand posture for utilization of gravity or a table's support.

In numerical simulations, we investigated the strategy performances and applicable conditions. Based on these results, we proposed some effective strategies according to the initial grasping point and an object length.

Finally we applied the practical three strategies to a hand-arm cooperation system and confirmed its reality.

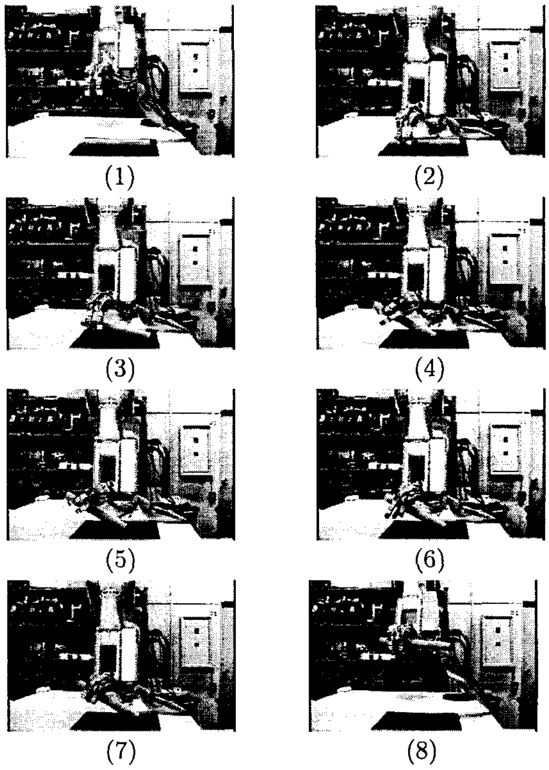

Figure 11: Pinching-grasping transition of strategy 2

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