Proceedings of the 3rd
International Conference on Advanced Mechatronics
Okayama, JAPAN · Aug. 1998, JSME

Scale-Dependent Grasps

Tatsuya Shirai Makoto Kaneko Kensuke Harada Toshio Tsuji
Industrial and Systems Engineering
Hiroshima University
Higashi-Hiroshima, 739-8527, Japan

Abstract

This paper discusses the scale-dependent grasps. Suppose that an object is initially placed on a table without touching by human hand and, then he (or she) finally achieves an enveloping grasp after an appropriate approach phase. Under such initial and final conditions, human unconsciously changes the grasp strategy according to the size of object, even though they have similar geometry. We call the grasp planning the scale-dependent grasp. Along the grasp patterns observed in human grasping, we apply a couple of grasp procedures to multi-fingered robot hands.

Key Words: Scale-Dependent grasps, multi-fingered robot hand, column object.

1 Introduction

There have been a number of works concerning multi-fingered robot hands. Most of them address a finger tip grasp, where it is assumed that a part of inner link never makes contact with the object. Enveloping grasp (or power grasp) provides another grasping style, where multiple contacts between one finger and the object are allowed. Such an enveloping grasp can support a large load in nature and is highly stable due to a large number of distributed contact points on the grasped object. While there are still many works discussing enveloping grasps, most of them deal with the grasping phase only, such as contact force analysis, robustness of grasp, contact position sensing, and so forth. Suppose that human eventually achieves an enveloping grasp for an object placed on a table as shown in Fig.1. Actually, such a situation is often observed in a practical environment, for example, in grasping a table knife, an ice pick, a hammer, a wrench, and so on. In many cases, the tool handle can be modeled as a cylindrical shape. For a cylindrical object having a sufficiently large diameter, human wraps it directly without any regrasping process, since the table makes no interference with the finger links at all. As the diameter decreases, human is obliged to utilize a different strategy so that he (or she) may avoid interference caused by the table. By simple experiment, we can show that human chooses the grasp planning according to the scale of objects, even though they are geometrically similar. We call the grasp planning the scale-dependent grasp planning. We would note that the scale-dependent grasp does not mean the final grasp style but means the change of the grasp patterns existing between the initial and final states according to the size of objects.

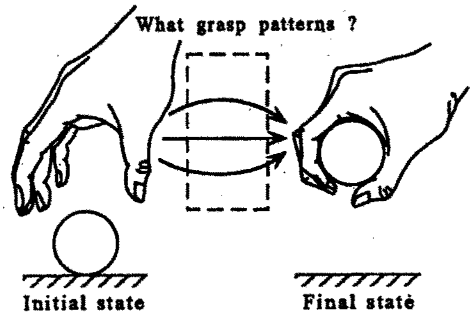


Fig.1 Enveloping grasp for an object placed on a table.

In this paper, we first observe the human behavior for grasping column objects with different size, shape of cross section and surface friction.

Our goal is to extract essential motion from human behavior and apply them to a multi-fingered robot hand. As for cylindrical objects with relatively small contact friction, the robot hand can achieve an enveloping grasp by utilizing three patterns, depending on the size of object. For a relatively large object, the hand can directly grasp it (*direct grasp*). For an object with middle size, the hand can utilize the wedge-effect, where a simple pushing motion at the bottom part of object automatically produces an upward force for lifting up the object (*sliding based grasp*). For a small object, the hand picks up object by thumb and index (or middle) finger tip then regrasp it by the remaining fingers (*regrasping based grasp*). For cylindrical objects, we pick up three patterns according to the size of object and rearrange those motion plans so that a multi-fingered can easily apply them. We also focus on different objects, apart from cylindrical objects and found that the grasp strategies taken for cylindrical objects are not always applicable to a general column object, especially for the object whose cross section is either triangle or square. For those objects, we prepare a rotating motion as an initial adjustment phase for producing a gap between the bottom part of the object and the table, so that the finger tip may be easily inserted in it. We also discussed the effect of contact friction on the grasp strategy. Under a significant contact friction, the sliding based grasp does not work any more. For such a situation, we provided *rolling based grasp* as an alternative procedure. The proposed grasping strategies are also verified experimentally by using a three-fingered robot hand.

2 Related Work

Human grasping based approach: In robotic hands, there have been a number of papers learnt by human behaviors[1]–[5]. Cutkosky[1] have analyzed manufacturing grips and correlation with the design of robotic hands by examining grasps used by humans working with tools and metal parts. Stansfield[3] discussed the robotic grasping based on knowledge. These works [1]–[3] focus on either the final grasp mode or finding an appropriate grasp posture under a set of grasp modes, target geometric characteristics and task description. Jeannerod[4] has shown that during the approaching phase of grasping, the hand preshapes in order to prepare the shape matching with the object to be grasped. Bard and Troccaz[5] introduced such a preshaping motion into a robotic hand and proposed a system for preshaping a planar two-fingered hand by utilizing low-level visual data.

Enveloping grasp or power grasp: Mirza and Orin[6] applied a linear programming approach to formulate and solve the force distribution problem in power grasps, and showed a significant increase in the maximum weight handling capability for completely enveloping type power grasps. Trinkle[7] analyzed planning techniques for enveloping, and frictionless grasping. Salisbury[8] has proposed the Whole-Arm Manipulation (WAM) capable of treating a big and heavy object by using one arm which allows multiple contacts with an object. Bicchi[9] showed that internal forces in power grasps which allow inner link contacts can be decomposed into active and passive. Kleinmann et.al.[10] showed a couple of approaches for finally achieving power grasp from finger tip grasp. Under constant torque control, Kaneko, Higashimori and Tsuji[11] discussed the transition stability by utilizing *the force-flow diagram* while the object is lifted up from the table to the palm.

Kaneko, Tanaka, and Tsuji[12] first discussed the scale-dependent grasp based on the observation of human grasping.

3 Observation of Human Grasping

In order to observe human behavior, we ask a subject to achieve an enveloping grasp for an object placed on a table, as shown in Fig.1. For column objects, we observe how human changes his (or her) grasping strategy according to the size, the shape of cross section of object, and the contact friction. Fig.2 shows the objects used in our experiments, where the white and the black objects denote that they are covered by a drawing paper and a rubber, respectively, so that we can change the surface friction. We use the normalized length d defined by $d = L_o/L_h$, where L_h and L_o, respectively, denote the length measured from the tip of thumb to the tip of index finger, and the circumference of object, as shown in Fig.3. The discussion utilizing d is very convenient since it is non-dimensional and, therefore, suppresses the scale effect brought by the hand size. We have done the grasp experiment for twenty-five subjects.

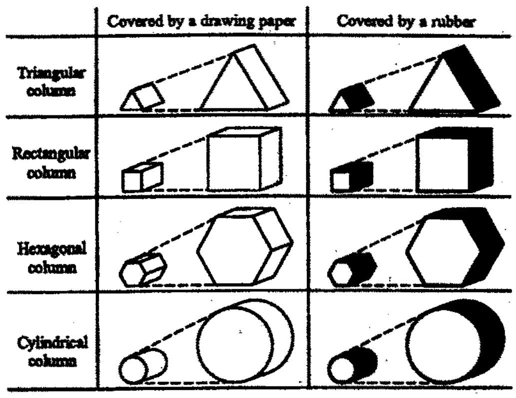


Fig.2 Column objects used in the experiments.

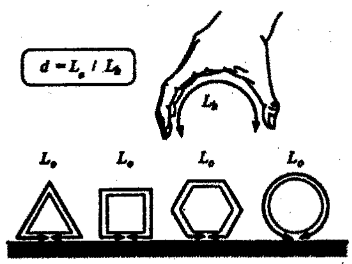


Fig.3 Explanation of L_o and L_h.

Fig.4(a) through (d) show the experimental results for column objects whose surfaces are covered by drawing papers(left side) and rubbers(right side), where "No." denotes the number of subjects who took the particular grasp pattern, and Fig.4(a), (b), (c) and (d) correspond to the objects whose cross sections are triangle, rectangle, hexagon and circle, respectively.

Pattern 1: Without any re-grasping motion, human directly grasps the object as shown in Fig.5(a). (*Direct grasp*)

Pattern 2: Finger tips are pushed between the bottom part of object and table, such that the object can be lifted up automatically, as shown in Fig.5(b). (*Sliding based grasp*)

Pattern 3: The object is first picked up by thumb and the remaining four fingers, and then the object is rolled up over the surface of thumb as shown in Fig.5(c). (*Rolling based grasp*)

Pattern 4: The object is first picked up by thumb and index (or middle) finger tip. The remaining fingers hook the object and then squeeze it till the finger tip grasp is broken and the object contacts the palm, as shown in Fig.5(d). (*Regrasping based grasp*)

For a large object whose d is greater than 1.0, human directly grasps it (*pattern1*), irrespective of both object's shape and contact friction. As the size of object decreases, pattern 2 through 4 appear according to the personal choice as well as the conditions set for the ex-

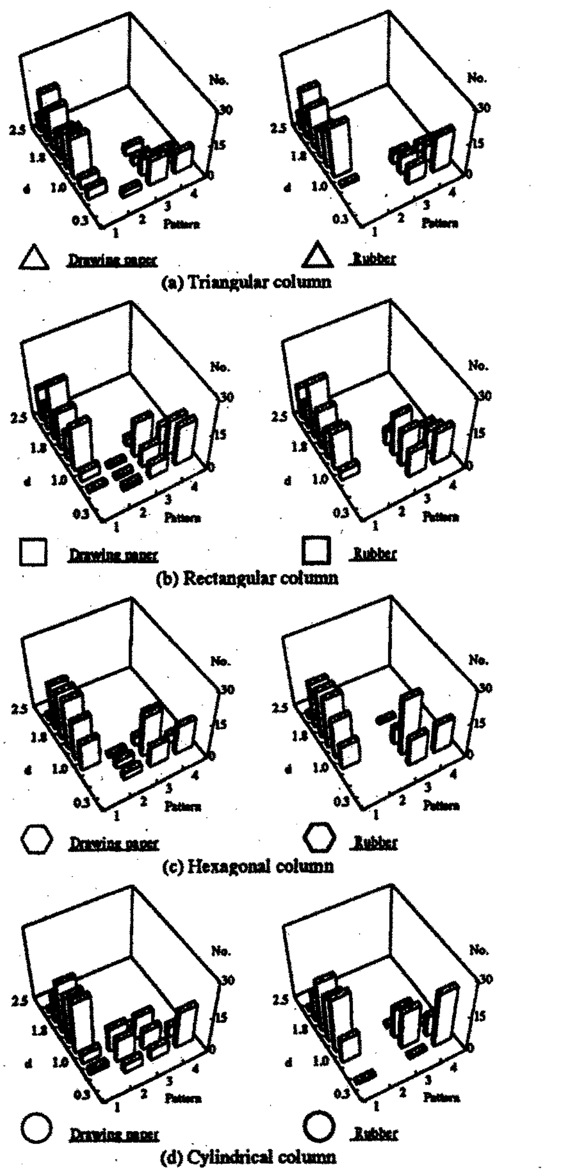


Fig.4 Grasp pattern classification map.

periment. Pattern4 especially becomes dominant for a small object. For such a small object, human tries to avoid interference between the finger tip and the table. As a result, human first picks up the object and achieves the target grasp through regrasping process from finger tip grasp to enveloping grasp. An interesting observation is that for cylindrical objects, some subjects take the sliding based grasp, where a lifting force can be expected by a simple pushing motion at the bottom part of object.

For objects with significant friction, the grasp pattern2 (*sliding based grasp*) disappears and, instead, both rolling based and regrasping based grasps become dominant. Such a change of grasp pattern is naturally understandable, because it is hard to achieve a sliding motion under a significant friction while both rolling

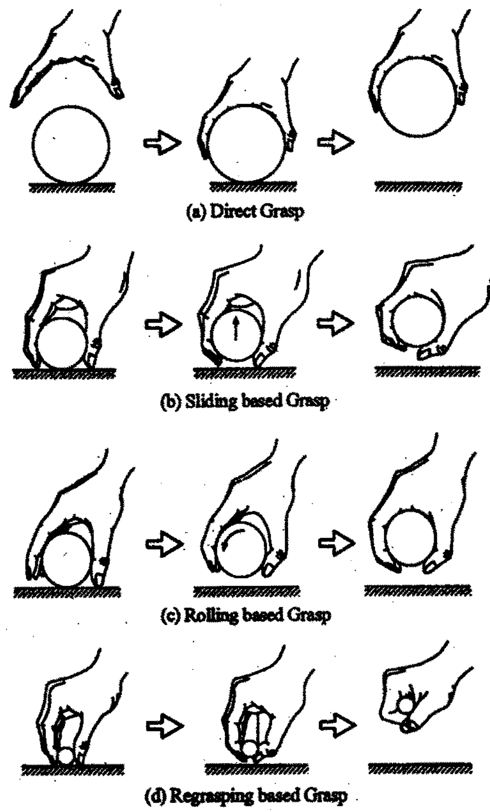


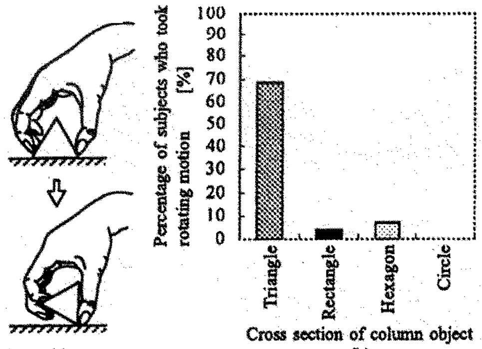
Fig.5 Grasp patterns.

and regrasping motions can be realized irrespective of the contact friction.

Another interesting behavior is observed for the initial phase in grasping triangular objects. Almost 70% of subjects first rotate the object around an edge so that a couple of fingers can be inserted in the gap produced, as shown in Fig.6, where (a) explains the basic motion at the initial phase and (b) shows percentage of subjects utilizing the rotating motion. For grasping a triangular object, such a rotating motion is quite essential for detaching the object from the table. We call this motion the initial adjustment motion. We note that the initial adjustment motion dominantly appears only for triangular objects.

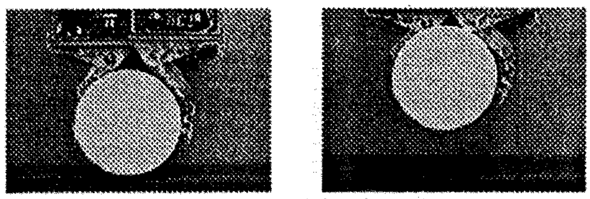
4 Application to Robot Hands

Our goal is not only to observe the human grasping but also to prepare the grasp strategy applicable to a multi-fingered robot hand. One way is to measure the human motion and directly send the position data to the robot hand, so that it can realize the same motion that human does. This approach, however, will not work successfully. This is because each robot hand has its own configuration, degrees of freedom, and the number of fingers, which are so different from those of human hand. Instead of imitating the exact motion done by human, we extract the essential motions and implement the key motion into a multi-fingered robot. While experiments by human provide a number



(a) (b)

Fig.6 Initial adjustment motion



(a) Approaching phase (b) Lifting/Grasping phase

Fig.7 Direct grasp.

of person-dependent grasp patterns, we roughly classify the grasp patterns into four, direct grasp, sliding based grasp, regrasping based grasp and rolling based grasp. Each strategy is associated with scale and cross section of column objects and friction.

4.1 Enveloping cylindrical objects

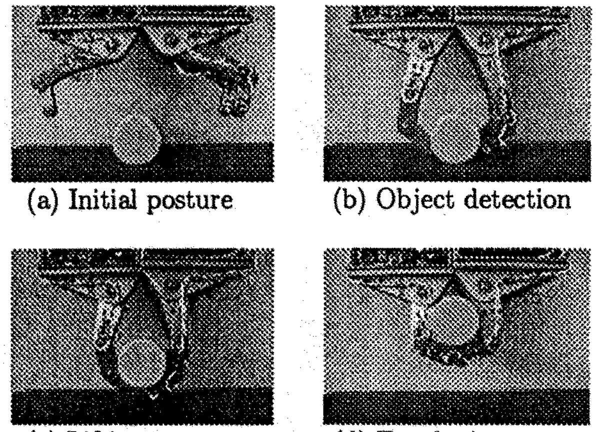
We assume that the robot hand including position sensor and torque sensor for each joint, we also assume a vision system for recognizing the object's shape as well as it position.

(a) Direct grasp

Direct grasp can be achieved straightforward. The robot hand is first fully opened and approaches the object until either the palm or part of finger makes contact with the object. When part of finger link makes contact with the object, the hand is moved so that it may be centered at the object. Then, each finger is closed by applying constant torque control as shown in Fig.7(a). After grasping object the robot hand lifts up as shown in Fig.7(b).

(b) Sliding based grasp

Initially each finger is opened as shown in Fig.8(a) and then approaches the table until the finger tip makes contact with it, where the table detection can be easily checked by torque sensor outputs. In the next step, each finger tip follows along the table until a part of finger link makes contact with the object as shown in Fig.8(b). Then, each finger tip pushes the object each other, so that we can make the most use of wedge-effect. The object will be automatically lifted up by the slip between the finger tip and the object surface as shown in Fig.8(c). At the same time each link is



(a) Initial posture (b) Object detection

(c) Lifting (d) Enveloping

Fig.8 Sliding based grasp.

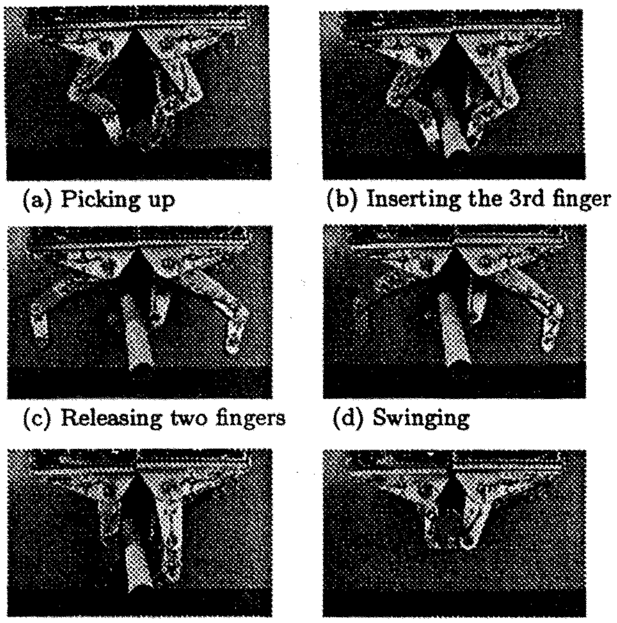
closed to remove the degrees of freedom of the object gradually. In this strategy, constant torque control is also effectively utilized for achieving both lifting and grasping phases. Whether the object really reaches the palm or not, and how firmly the hand grasps the object, strongly depend on how much torque command is imparted to each joint.

(c) Regrasping based grasp

For an object whose diameter is small enough to ensure that any finger tip can not be inserted in the bottom part of object, it is difficult to utilize the wedge-effect. In such a case, regrasping based grasp may be an appropriate strategy for finally enveloping the object. Regrasping based grasp can be decomposed into two basic motions. One is the motion for picking up the object by using two fingers as shown in Fig.9(a), and the other regrasping motion as shown in Fig.9(b) through (e). The first motion plays an important role in allowing no interference from the table. In the following motion, the remaining finger hooks the object so that we can make a small gap between the object and the table as shown in Fig.9(b), even though two fingers picking the object are released from the object. After those finger motions, the object is supported by one finger and the table as shown in Fig.9(c). We note that under such object's posture we can find an enough space between the object and the table for the released fingers to be inserted. In the next step, the left finger is swung a bit as shown in Fig.9(d) so that it may not be interfered with the right fingers during the finger closing motion. After every finger is inserted into the bottom of the object as shown in Fig.9(e), constant torque control is applied for achieving an enveloping grasp as shown in Fig.9(f).

(d) Rolling based grasp

For sliding based grasp, we implicitly assume that the contact friction is small enough to smoothly achieve a sliding motion during the lifting phases. Under significant friction, however, the sliding based procedure will eventually fail in enveloping an object, since a sliding



(a) Picking up (b) Inserting the 3rd finger

(c) Releasing two fingers (d) Swinging

(e) Regrasping (f) Enveloping

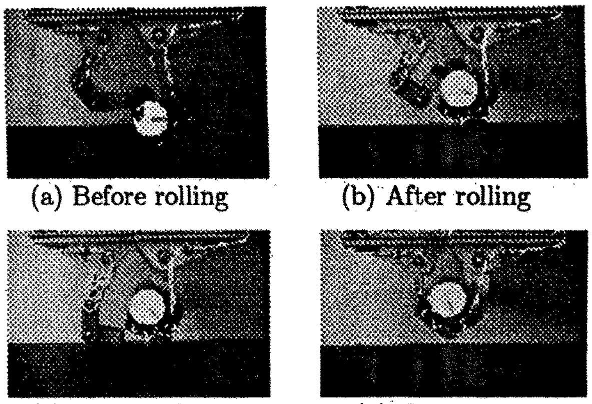
Fig.9 Regrasping based grasp.

motion is not always guaranteed between the robot finger and the object. This failure can be detected by monitoring both position and torque sensor's outputs. At the moment such failure happens, each torque sensor output sharply increases, while finger posture does not change at all.

In such a case, we switch from a sliding based strategy to rolling based grasp strategy after the object is put down on the table. Fig.10 shows an example of rolling based grasp. First, the left finger starts to make the object roll over along the surface of right fingers being in slowly closing as shown in Fig.10(a) through (b). After confirming that the center of gravity exists between the two right fingers, the left finger is released as shown in Fig.10(c) and finally an enveloping grasp is completed as shown in Fig.10(d).

4.2 Enveloping other column objects

For a cylindrical object, there usually exists an enough space to insert a finger tip between the bottom part of the object and the table, unless the object's diameter is smaller than that of finger tip. As a result, the finger tip can easily produce the upward force unless the contact friction is dominant. For a general column object, however, depending upon the object's shape, the finger tip forces may balance within the object or they may produce the downward force even if the contact friction is small. Under such situations, the lifting force is not produced, even though we increase the contact force. For example, such situations will be observed for the objects shown in Fig.11(a). Such a failure in lifting can be easily detected by the joint torque sensor, because their outputs will sharply increase during a pushing motion in the horizontal direction. For such an object, an initial adjustment phase is necessary for



(a) Before rolling (b) After rolling

(c) Finger releasing (d) Enveloping

Fig.10 Rolling based grasp.

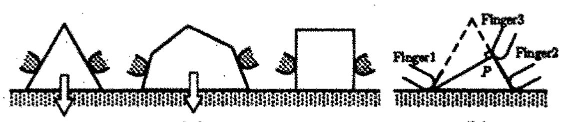


Fig.11 Examples of objects where the upward force is not expected by a simple pushing motion, and Pushing point P_c for triangular object.

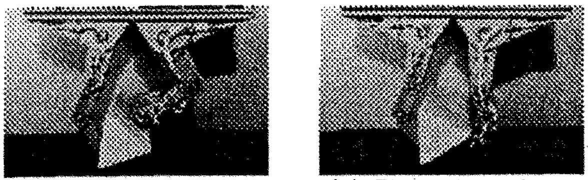
producing an enough space to insert fingers between the object and the table. As grasp experiments by human suggest, the rotating motion should be a key for partly detaching an object having rectangular or triangular cross section from a table.

Suppose an extreme case, where the friction between the finger tip and the object is zero. Even for such an extreme case, in order to produce a rotating moment around one side of the support polygon, we have to impart a pushing force at the upper point than P_c, where P_c is the intersection between the object surface and the normal line from the supporting edge, as shown in Fig.11(b). However, P_c does not always exist over the object surface since it strongly depends on the object's geometry. When P_c is not detected, we assign the top point as P_c in which the finger tip can apply the largest moment under a constant pushing force. Suppose that the object's shape can be detected by a vision, we can obtain the pushing point for rotating motion as well as the position of the object.

After a sufficient gap is produced as shown in Fig.12(a), one finger is removed away from the object's surface to be inserted into the gap as shown in Fig.12(b). After the finger tip is sufficiently inserted into the gap between the object and the table, we apply the same grasping mode as that taken for cylindrical objects. More precise discussions on sensing are described in [13].

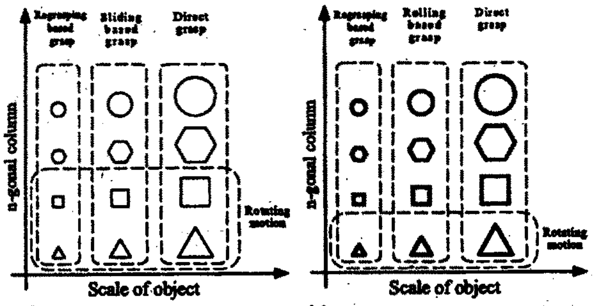
5 Discussion

In section 4, we proposed four different strategies and the initial adjustment phase, while the initial adjust-



(a) Rotating (b) Finger inserting

Fig.12 Initial adjustment motion (Rotating motion).



(a) Under small friction (b) Under significant friction

Fig.13 The map for choosing an appropriate strategy for achieving envelop grasp.

ment phase included depends upon the object's shape. In this section, we summarize how we switch from one to another strategy. Fig.13 shows a guide-line-map for choosing an appropriate strategy for an arbitrary object. We note that the contact friction is not known until at least fingers make contact with the object, while the object's geometry is known in advance by a vision system. Therefore, the robot hand can not make decision in advance whether the sliding or the rolling based grasp is better, while it can prepare an appropriate strategy depending upon the object's shape. In general, the motion planning for the sliding based grasp is simple enough compared with that for the rolling based grasp. Due to the fact, when the vision system provides the size whose appropriate strategy is either the sliding or the rolling based grasp, the robot hand first takes the strategy of the sliding based grasp. If it fails in finally achieving the grasp, then it switches from the sliding based grasp to the rolling based one.

6 Conclusion

We discussed the Scale-Dependent Grasp by observing the grasp pattern produced by human. Based on the observation of human grasping, we chose four grasp patterns which are easily applicable for a multi-fingered robot hand. We showed a guide-line-map for choosing the most appropriate strategy depending upon the constant friction as well as the geometry.

This work is supported by Inter University Robotic Project provided by Ministry of Education Japan. Finally the authors would like to express their sincere thanks to Mr.N.Thaiprasert, Mr.Y.Hino, Mr.M.Higashimori, Mr.Y.Tanaka, and Mr.K.Nakagawa for their cooperation for this work.

References

[1] Cutkosky, M.: On grasp choice, grasp models, and the design of hands for manufacturing tasks, *IEEE Trans. on Robotics and Automation*, vol.5, no.5, pp269–279, 1989.

[2] Bekey, G.A., H. Liu, R. Tomovic, and W. Karplus: Knowledge-based control of grasping in robot hands using heuristics from human motor skills, *IEEE Trans. on Robotics and Automation*, vol.9, no.6, pp709–722, 1993.

[3] Stansfield, S.: Robotic grasping of unknown objects: A knowledge based approach, *Int. J. of Robotics Research*, vol.10, pp314–326, 1991.

[4] Jeannerod, M.: Attention and performance, chapter Intersegmental coordination during reaching at natural visual objects, pp153-168, Erlbaum, Hillsdale, 1981.

[5] Bard, C., and J. Troccaz: Automatic preshaping for a dexterous hand from a simple description of objects, *Proc. of the IEEE Int. Workshop on Intelligent Robots and Systems*, pp865-872, 1990.

[6] Mirza, K., and D. E. Orin: Control of force distribution for power grasp in the DIGITS system, Proc. of the IEEE 29th CDC Conf., pp1960-1965, 1990.

[7] Trinkle, J. C., J. M. Abel, and R. P. Paul: Enveloping, frictionless planar grasping, *Proc. of the IEEE Int. Conf. on Robotics and Automation*, 1987.

[8] Salisbury, J. K., Whole-Arm manipulation, *Proc. of the 4th Int. Symp. of Robotics Research, Santa Cruz*, CA, 1987. Published by the MIT Press, Cambridge MA.

[9] Bicchi, A: Force distribution in multiple whole-limb manipulation, *Proc. of the IEEE Int. Conf. on Robotics and Automation*, pp196-201, 1993.

[10] Kleinmann, K. P., J. Henning, C. Ruhm, and H. Tolle: Object manipulation by a multifingered gripper: On the transition from precision to power grasp, *Proc. of the IEEE Int. Conf. on Robotics and Automation*, pp2761-2766, 1996.

[11] Kaneko, M., M. Higashimori, and T. Tsuji: Transition Stability of Enveloping Grasps, *Proc. of the IEEE Int. Conf. on Robotics and Automation*, 1998 (to appear).

[12] Kaneko, M., Y. Tanaka, and T. Tsuji: Scale-dependent grasp, *Proc. of the IEEE Int. Conf. on Robotics and Automation*, pp2131-2136, 1996.

[13] Kaneko, M., N. Thaiprasert, and T. Tsuji: Experimental Approach on Enveloping Grasp for Column Objects, *Preprint of 5th Int. Symp. on Exp. Robotics*, pp17-29, 1997.