GRASPING OF UNKNOWN OBJECT
IMITATING HUMAN GRASPING REFLEX

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Abstract: This paper presents a grasping strategy of unknown objects imitating human grasping reflex for anthropomorphic robot hands. In the proposed grasping, each joint of the thumb and the fingers is controlled independently using the contact force affecting its adjacent fingertip side link. By setting a suitable contact force, both fingertip grasping and enveloped grasping with uniform grasping force are executable. Experimental results of three-dimensional unknown object grasping using an anthropomorphic robot hand, named Gifu Hand, with a distributed tactile sensor, are shown. Copyright © 2002 IFAC

Keywords: robot, hand, grasp, reflex, velocity control, force control, multi-fingers

1. INTRODUCTION

In order to establish the dexterous robot hand technology, many researches, such as multi-fingered hand mechanism (Jacobsen 1984; Jau 1995; Lin 1996; Kyriakopoulos 1997; Liu 1999; Kawasaki 1998; Kawasaki 1999; Lovchik 1999), tactile sensor (Shimojo 1995; Johnston 1996; Jockush 1997), fingertip grasping (Cole 1989; Yoshikawa 1991; Maekawa 1997), enveloped grasping and power grasping (Salisbury 1987; Trinkle 1987; Mirza 1990; Sugiuchi 2000), manipulation of an enveloped object (Kaneko 1996; Yu 1998), planning (Fischer 1997) etc., have positively been promoted. Most of these researches assume that a grasped object model is known and all information needed for the grasping can be obtained. Hence, it is difficult to apply these methods for grasping unknown objects.

A few researches (Maekawa 1997; Fischer 1997; Tada 1999; Endo 1993) proposed a control method to grasp an unknown object using a tactile sensor or a force sensor. It seems that these approaches do not coincide with the human grasping reflex because applied controls are relatively complex and abduction/adduction of a finger motion is not realized using a distributed tactile sensor. A human can manipulate an unknown object using information from a distributed tactile organ. One of the essential abilities of object grasping and manipulation is grasping reflex, which appears during the postnatal period. This grasping reflex is considered to be an essential action to get and keep an object for the survival. It seems that the object is grasped with uniform contact force even if the object geometrical form is unknown. It is considered that a robot hand having skill of grasping reflex can grasp easily various unknown objects including flexible objects.

This paper presents a grasping strategy imitating human grasping reflex in order to grasp various unknown objects. The proposed grasping strategy is based on a finger joint independent control using adjacent fingertip side tactile information. By adjusting force feedback gain and force integral gain of each joint, both fingertip grasping and enveloped grasping with uniform contact force are executable. Experimental results of the proposed grasping strategy are shown using an anthropomorphic robot hand named Gifu Hand II (see Kawasaki 2001) with a distributed tactile sensor of 624 detecting points.
2. ANTHROPOMORPHIC ROBOT HAND

2.1 Gifu Hand II

An overview of the developed anthropomorphic robot hand named Gifu Hand II (see Kawasaki 2001) is shown in Fig. 1. The right and left hands are designed symmetrically and each of them has a thumb and four fingers. The thumb mechanism is shown in Fig. 2. The servomotors and joints are numbered from the palm to the fingertip. The thumb has 4 joints with 4 DOF and each of the fingers has 4 joints with 3 DOF. The movement of the first joint of each of the thumb and the fingers allows abduction and adduction, and the movement of the second joint to the fourth joint allows flexion and extension. The main difference between the thumb and the fingers is that the fourth joint of the fingers is engaged with the third joint which is driven by the third servomotor, through a planar four-bar linkage mechanism. Thus, the Gifu hand II has 20 joints with 16 DOF. Each servomotor (Maxson DC motor by Interelectric AG) has a magnetic encoder with 16 pulses per revolution. Each finger of the robot hand was designed to be equipped with a 6-axes force sensor (Nano sensor by BL. AUTOTEC Co.) for compliant pinching. The weight of the hand is 1.4Kgf and the bandwidth at a velocity control of the fingers is more than 7 Hz, which gives higher response than the human fingers. The hand is compact, lightweight, and anthropomorphic in terms of geometry and size, such that it performs grasping and manipulation like the human hand.

2.2 Distributed Tactile Sensor

The shape of the developed tactile sensor is shown in Fig. 3. The tactile sensor has grid pattern electrodes that use conductive ink in which the electric resistance changes in proportion to the pressure on the top and bottom of a thin film. The characteristics of the tactile sensor are shown in Table 1. The number of detecting points on the palm, the thumb, and each of the fingers is 312, 72, and 60, respectively, and the total number of measurement points is 624. The electrode width is 2 mm, the column pitch is 4 mm, and the row pitch is 6 mm. The Maximum load is about $7.4 \times 10^4$ N/m$^2$, the resolution of measurement is 8 bits, and the sampling cycle is 10 ms/flip. The detected data on the sensor sheet is transported to a PC through a special interface board. This tactile sensor has nonlinear characteristics such as hysteresis, creep, and dispersion in measurement sensitivity. A signal processing taking such nonlinear characteristics into account is required.

3. GRASPING STRATEGY

<table>
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<tr>
<th>Table 1 Characteristics of distributed tactile sensor</th>
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<tr>
<td>Number of detecting points</td>
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<td>Palm</td>
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<td>Thumb</td>
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<td>Maximum load</td>
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<td>Electrode width</td>
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<td>Column pitch</td>
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<td>Resolution</td>
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<td>Thickness of sensor sheet</td>
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<td>Weight</td>
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3.1 Grasping Reflex

The grasping reflex is commented briefly in the following. A baby by about 10 months of age may bend his/her thumb and 4 fingers and grasp a rod when it is in contact with the palm. After grasping, if the rod is plucked from the baby’s hand, the baby holds the rod more strongly. The reaction of the hand is called a grasping reflex. In addition, pronation and supination of the wrist may happen only by lightly touching the palm, for babies of about 10 months, and the hand approaches the inciter and the reaction for grasping strengthens.

There are two kinds of actions in the reflection of the hand (Wing 1996): spinal reflex that is realized only at the spinal cord level, and cerebrum cortex reflex that needs the neocortex level. The spinal reflex is an action for motion adjustment and protection of the hand, and the cerebrum cortex reflection is an action to the externality by extending the hand. The grasping reflex, which is the reflection of the cerebrum cortex level, is generated by either the mechanoreceptors of the palm or the deep receptors of the muscle. The route of the reflection is shown in Fig. 4. This grasping reflex is generated by the muscle action of all the fingers, and not generated by the contraction of individual muscles as for the pinching.

3.2 Grasping Strategy

Let us consider the grasping strategy of an unknown object. Fig. 5 shows a contact state between an i-th finger and an object, where \( \theta_{ij} \) and \( F_{ij} \) are respectively the angle of the j-th joint and the total contact force of the j-th link, of the i-th finger. The grasping reflex includes two stages: grasping action, which occurs at the object contact with the hand, and keeping action, which occurs at the object removal from the hand.

First, let us consider a grasping action in which each finger contacts the object with a uniform force. This approach will enhance the possibility of grasping unknown objects because the number of contact points is maximized and the object is enveloped by the thumb and the fingers. When the object contacts the hand, joints 2 to 4 of the thumb and the fingers are controlled independently to generate flexion such that the force of adjacent fingertip side link of each joint equals a desired force. It seems logic that a velocity control is adopted at non-contact state and a force control is adopted at contact state. Motor input \( E_{ij} \), which drives the j-th joint of the i-th finger, is given by

\[
E_{ij} = -K_{v_{ij}}(\theta_{ij} - \dot{\theta}_{ij}) \quad (i = 1, \ldots, 5; \ j = 2, \ldots, 4) \tag{1}
\]

where \( K_{v_{ij}} \) is the velocity feedback gain of the j-th joint of the i-th finger, and \( \dot{\theta}_{ij} \) is the desired velocity of the j-th joint of the i-th finger. The desired velocity of each joint is given by

\[
\dot{\theta}_{ij} = \begin{cases} \dot{\theta}_{ij} : \text{non-contact state} \\ -K_{f_{ij}}(F_{ij} - F_{d_{ij}}) - K_{\psi_{ij}}\int (F_{ij} - F_{d_{ij}}) \, dt \end{cases} \tag{2}
\]

Contact state

where \( K_{f_{ij}} \) is the force feedback gain, and \( K_{\psi_{ij}} \) is the force integral gain. This shows that the link at contact state is controlled by force feedback control. The fourth joint each of the fingers, excluding the
The desired force of the third joint is obtained by contact with the object, may happen. Therefore, the desired joint angle is the desired joint angle. The desired joint angle is realized according to the object size. In order to realize this action, joint 1 of each of the thumb and the fingers is controlled by position and velocity control given by

\[ E_{\alpha} = -K_{p,i}(\theta - \theta_{d,i}) - K_{v,i}\dot{\theta}_{d,i} \quad (i = 1, \ldots, 5) \quad (3) \]

where \( K_{p,i} \) is the position feedback gain, and \( \theta_{d,i} \) is the desired joint angle. The desired joint angle is designed as such a center line on the surface of each of the thumb and the fingers, which coincides with a contact line, which is lined from the axis of the first joint to the contact points using the least square method, as shown in Fig. 6.

The previously mentioned strategy is very simple, however it realizes a dexterous grasping. When the object contacts the palm, each link is driven toward thumb, of Gifu Hand cannot be driven directly because it is engaged with the third joint through the planar four-bar linkage mechanism. Hence, the case where only either the third link or the fourth link is in contact with the object, may happen. Therefore, the desired force of the third joint is obtained by adopting the largest of \( F_{i3} \) and \( F_{i4} \).

The first joint is controlled to generate abduction and adduction according to the object size. In order to realize this action, joint 1 of each of the thumb and the fingers is controlled by position and velocity control given by

\[ E_{\alpha} = -K_{p,i}(\theta - \theta_{d,i}) - K_{v,i}\dot{\theta}_{d,i} \quad (i = 1, \ldots, 5) \quad (3) \]

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![Fig. 7 Control system](image1)

![Fig. 8 Process of Spherical object grasping](image2)

![Fig. 9 Force responses at spherical object grasping](image3)
realizing a contact. If the fingertips contact the object and the hand base side link does not contact the object, then the contact forces at the fingertips increase by the control of the second joint of each finger. This leads a desired motion of the third joint that brings to disengage from the object surface. On the contrary, if the hand base side link contacts the object and the fingertips are in a non-contact state, the fingertips are driven toward the object surface. Finally, all contact forces are adjusted uniformly. It is noted that the pinching by fingertips is possible by setting a suitable $K_{ij}$. 

4. EXPERIMENT

The experimental system is shown in Fig. 7. The haptic sensor output is processed by a DOS/V PC with a 10ms period. The measured haptic data is transported to a hand control PC through a common memory (named Memolink, by Interface Co.). The sampling cycle of the hand controller is 2 ms.

Fig. 8 shows the sequence of grasping a spherical object with a diameter of 9.5 cm. The desired contact force is of 0.3 N. The contact force responses are shown in Fig. 9. They show that the contact force of each link is close to the desired force. It happens that either link 3 or link 4 of a finger does not contact the object because the fourth joint is engaged with the third joint. In human fingers, the forth joint curves at strong grasping and makes the grasping more stable.

Fig. 10 shows the process of grasping a cylindrical pet bottle with a diameter of 6 cm. The desired contact force is 0.3N, which is the same as for the spherical object. The bottle was set to contact the palm crossly, however each of the fingers links bent to meet the object form.

An experiment of grasping a paper cup of a diameter of 6.5 cm, is shown in Fig. 11. The paper cup is very flexible. Fig. 11 (1) is the case where each joint of the fingers is actuated by a velocity control. Fig. 11 (2) is the case where each joint is driven by the proposed grasping reflex control with a desired
contact force of 0.15 N. The deformation of the cup is very big at the velocity control, however it is very small at the grasping reflex control. The contact force responses for the grasping reflex control are shown in Fig. 12. All the contact forces of the three links are larger than the desired contact force. The contact force responses for the grasping reflex control are shown in Fig. 13. The contact forces of link 1 and link 3 are close to the desired force. Link 2 did not contact the cup because link 3 contacted it with the desired force and the fourth joint is engaged with the third joint. However, the experiment shows that the proposed grasping reflex control is effective for unknown objects, even if the object is flexible.

5. CONCLUSION

This paper presented a grasping strategy imitating the grasping reflex of humans. The grasping reflex has two actions: grasping action which ensures positive grasping, and keeping action which prevents the release of the object. Experiments of the grasping of some objects have shown that the grasping reflex can be realized with a simple control strategy, which is, all the joints are driven independently by force control. It has been shown that the robot hand equipped with the grasping reflex is able to grasp geometrically unknown objects stably.

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Endo H. and M Wada (1993). Grasping Control Method of geometrically unknown objects stably. Equipped with the grasping reflex is able to grasp control. It has been shown that the robot hand of some objects have shown that the grasping reflex the release of the object. Experiments of the grasping positive grasping, and keeping action which prevents has two actions: grasping action which ensures


