Development of a Multi-fingered Mechanical Hand with Envelope Grasp Capability for Various Shapes of Parts

Nobuaki IMAMURA
Kobe City College of Technology
8-3 Gakuen-Higashimachi,Nishi-ku,KOBE,651-2194, JAPAN

Seiichi YAMAOKA
Toyo Press Industry Co.Ltd.
1-9-36 Nagasu-Nishitori.AMAGASAKI, 660-0807, JAPAN

Hidenori SHIRSAWA
The Advanced Materials Processing Institute Kinki Japan
7-1-8 Doi-cho,AMAGASAKI, 660-0807, JAPAN

and

Hiroyuki NAKAMOTO
Hyogo Pref. Institute of Technology
3-1-12 Yukihira-cho, Suma-ku,KOBE,654-0037, JAPAN

ABSTRACT

Recently, it has been required that various objects with different shapes or sizes could be held and grasped by one robot hand mechanism for the sake of factory automation and labor saving. Corresponding to such needs, we have developed an articulated mechanical hand which has an envelope grasp capability. Since the developed hand is possible to envelope and grasp an object mechanically, it can be used easily and widely in the factory where various shaped or different sized parts should be handled. In this paper, the detailed design of articulated mechanical hand with envelope grasp capability which we have newly developed by introducing GaeaDrive® and its motion mechanism are described.

Keywords: Articulated finger, Envelope grasp, GaeaDrive®, Mechanical hand, Multi-fingered robot hand, Semi-universal hand.

1. INTRODUCTION

The robot hand which could handle various shaped or sized parts has been required with the advance of factory automation and robotization of manufacturing. It is eagerly desired especially in the robotization of material or parts charging work to the machine assembly production line. At present, the mechanical gripper of the form which grasps the object by opening/shutting motion like the plier is widely utilized in industrial robot system. Though the mechanical gripper has the advantage that it is possible to hold the object surely by the simple mechanism, the object to be held is only a specific shaped or sized one and it should be placed in order. These facts has made the robotization of material or parts charging work in the production line difficult, where it is necessary to handle various objects which are stocked in disorder.

In our study, a multi-fingered articulated mechanical hand has been developed introducing miniaturized torque limiter mechanism to the joint driving system. The developed hand is possible to envelop and grasp the different shaped or sized object like a human hand. A distinctive feature of the developed mechanical hand is that it is possible to grasp the object in the predetermined contact force without sensory feedback control. This report describes the newly designed mechanical hand and joint mechanism which can adjust the contact force to object without sensors in detail.

2. DESIGN CONCEPT

Figure1 shows an advance of robot hand [1]. The mechanical gripper is widely used as a hand of the industrial robot, since a surely grasping is guaranteed if the object is uniform and it is placed at the fixedly decided position.

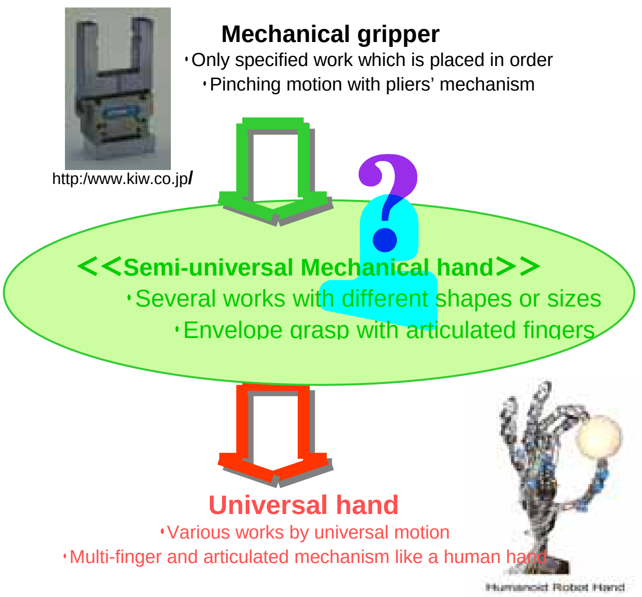


Figure 1 Advance of robot hand

However the mechanical gripper has an inexpedience that it must be exchanged when the object to be grasped is changed, because the mechanical gripper is very exclusively prepared for the specific shaped or sized object. Furthermore the mechanical hand could surely repeat a grasping motion towards the object aligned in the determined position and orientation because of its opening/shutting motion mechanism without feedback control, but it is inevitably impossible to continue the grasping task without correcting the hand position and orientation towards the object by controlling the robot arm adaptively when the error occurs in the position and orientation of the object.

On the other hand, human hand could grasp various shaped or sized objects placed in arbitrary position and orientation easily and surely by maneuvering five articulated fingers. Many researches and developments [2] [3] [4] [5] [6] [7] had been studied in order to realize a universal robot hand as like as human hand which has capability of dexterous grasping motion. However any practical universal hands widely used in the manufacturing scene have not been appeared yet.

It is necessary for the realization of universal hand to overcome technical difficulties how a large number of joint driving mechanisms and actuators should be included in the limited small space in mechanical design and how many pieces of circuits and cables should be implemented in the small structure in wiring design. Moreover the development of control software technology how to grasp various kinds of objects adaptively by the utilization of multiple sensor information and the motion control of hand mechanism with a lot of degrees of freedom is also necessary.

Barret Hand [8] and DLR-HandⅡ[9] etc. are challenges to the realization of practical universal hand. Barret Hand is composed of 3 fingers and each finger has 2 joints which rotate in the grasping direction. The 2-D.O.F. of a finger is driven by one DC servomotor through clutch mechanism called “TorqueSwitch”. It is possible to envelope various shaped or sized objects and grasp them firmly, but contact forces between the object and finger link are adjusted by the preset threshold torque of “TorqueSwitch” and the software of motor control. DLR-HandⅡis 4-fingered mechanism with 3 D.O.F./finger ×4-fingers and 1 D.O.F. in the palm and each D.O.F. is driven by DC servomotor. Moreover miniature six dimentional force/torque sensor is installed at the tip of each finger. All D.O.F. of the hand is controlled by software on the basis of sensory feedback. Though both of them realize a human-like universal hand with compact and light multiple degrees of freedom mechanism by introducing the new technology in drive mechanism design or circuit implementation, their motion control are carried out by computer software.

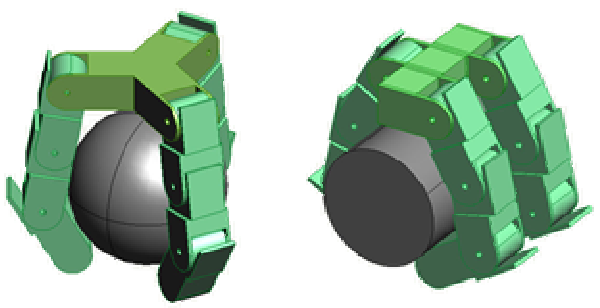


Figure 2 Conceptual image of the semi-universal mechanical hand

Based on these technical considerations on the functional advance of such robot hands, a hand with a capability of the envelope grasp for different shaped or sized objects in mechanical action like the mechanical gripper and without requiring complicated software control by sensory feedback like the universal hand is defined as the semi-universal mechanical hand in our study as shown in Figure 1. And the target of our development has been set at the semi-universal mechanical hand. Figure2 shows conceptual image of semi-universal mechanical hand.

3. MECHANISM OF THE MECANICAL HAND

In this study, articulated finger mechanism which can mechanically adjust joint torque without any sensory feedback control has been realized by newly designed miniature friction generation mechanism called GaeaDrive® and introducing it into the joint mechanism as a torque limiter device.

The distinguished features of the developed mechanical hand are (1) articulated finger mechanism, (2) mechanical drive without software control, (3) adjustable contact force toward object and (4) compact joint mechanism.

3.1 GaeaDrive®

GaeaDrive® is a simple friction generation mechanism which is made of a few mechanical parts. Its structure is shown in Figure3.

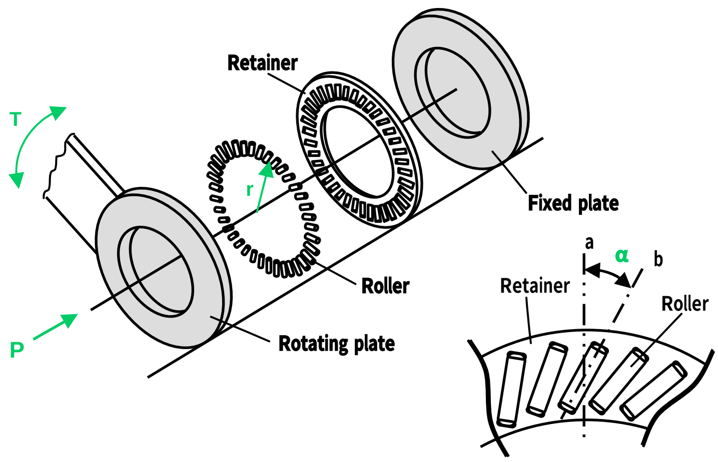


Figure 3 Mechanism of GaeaDrive®

GaeaDrive® is composed of a fixed plate, a rotating plate and rollers which are retained and put between a fixed and rotating plates. Rollers tilt as angle α and they are put on the pitch circle radius r at regular intervals.

When the rotating plate is forced to move, stable friction torque T is generated because of tilting rollers. T is expressed by

$$T = \mu r P \sin\alpha \qquad (1)$$

Where μ: friction coefficient between rollers and plates, r: pitch circle radius, P : pressing force and α: angle of tilting roller [10].

So, GaeaDrive® would be used as a torque limiter device, because friction torque T could be adjusted by changing the pressing force P from Eq. (1).

3.2 Joint driving mechanism

The driving mechanism of the articulated finger joint is shown in Figure4. Finger Link retained with the friction of GaeaDrive® is rotated with joint shaft when joint shaft is driven from motor. When finger link makes contact with the object to be grasped and reaction force torque reaches the friction torque set by GaeaDrive®, gliding motion begins in the joint driving mechanism and finger link stops, while the fixed force keeps working to the object.

However the joint shaft which is connected with next joint shaft by the belt continues to rotate from motor so that driving power could be transmitted to the next joint. Because the second joint driving mechanism is the same as the first joint, the second finger link rotates until it makes contact with object and stops to move when reaction force torque reaches the friction torque set by GaeaDrive®. The following serial links rotate in the same way and contact with object in order from the base link so that envelope grasp could be carried out while the fixed contact forces work toward object.

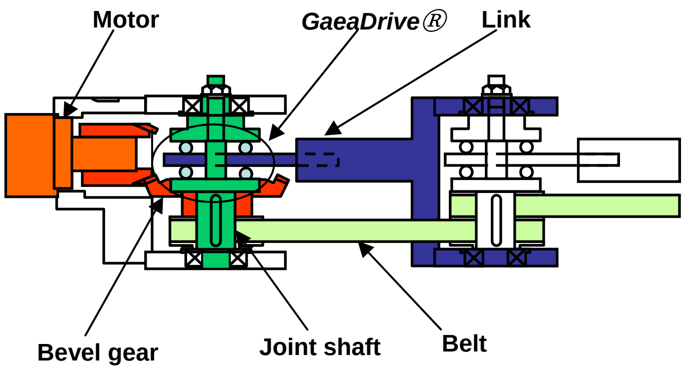


Figure 4 Joint mechanism

Figure5 shows dimension of the developed mechanical finger. The section size of it is 25×33.5(mm) and the length is 190(mm). Weight is 420(g).. The developed finger unit has three joints in which GaeaDrive® is installed as shown in figure4 and all joints are driven by one motor simultaneously. But three joints are not indispensable for the developed finger. It is possible to easily change the number of the joint, because the mechanism of each joint has been unitized and has been designed to the equal mechanism.

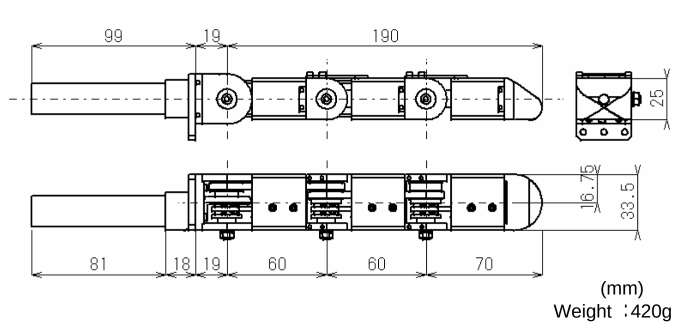
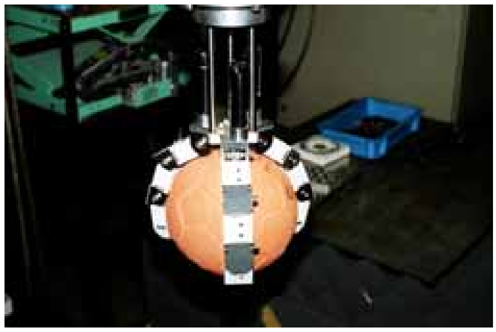


Figure 5 Dimension of the developed finger

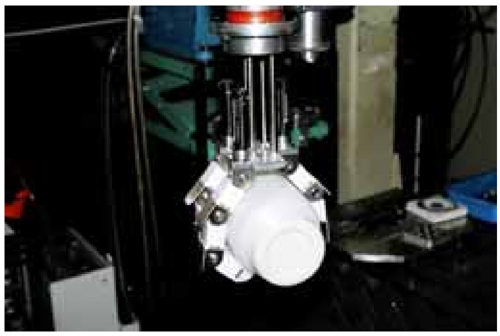
Figure6 shows an appearance of the developed mechanical hand. Both mechanical hands shown in the figurer6 is composed of three fingers and each finger has three rotational joints which include the above mentioned mechanism. Figure6(a) is constructed for the purpose of envelope grasp of the spherical shaped object. In this configuration, three fingers have been installed in the circumference of the discoidal palm plate. Figure6 (b) is constructed for the grasp of the cylindrical shaped object. Two fingers and one finger have been installed on the square palm plate and faced each other. Because of the unit design for finger mechanism it is easy to change hand configuration according to the shape of object.

In the production field, parts of various shapes are handled. It is possible to classify most of parts handled in the production field into parts of spherical shape or cylindrical shape. From this fact, it is considered that a grasp of all industrial part is almost possible by the developed mechanical hand.

Furthermore it is possible to alter the degrees of freedom of the finger for the different sized object as mentioned above. If an object to be handled is too large, the mechanical hand could deal with the object by increasing the degrees of freedom.



(a) Configuration for spherical object



(b) Configuration for cylindrical object

Figure 6 Mechanical hand

The envelope grasp by 3 DOF fingers shown in the Figure6 is carried out in sequential motion of 0, 1st, 2nd and 3rd phases. Sequential motion of envelope grasp is illustrated in Figure7.

At 1st phase, each finger is rotated on the first joint from initial configuration (phase0) when the first joint shaft is driven by motor. Because the joint shaft which rotates each link of finger is being coupled by the belt, the relative angular relationship of each link is fixedly kept during rotating motion. After that, the first link contacts the object receiving contact reaction force from it and reaction torque affects the torque limiter device GaeaDrive® installed in the joint mechanism. When the reaction torque exceeds the adjusted torque by GaeaDrivet®, it occurs gliding between the link and its driving shaft in the joint shaft mechanism and the link stops to rotate keeping contact force at the adjusted

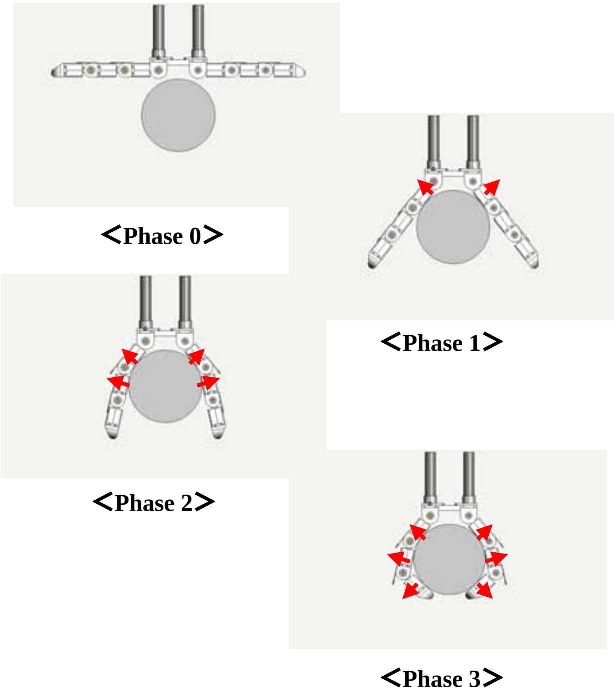
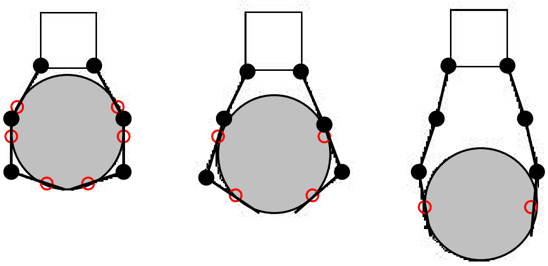


Figure 7 Motion of envelop grasp

value and maintaining a contact with the object . Simultaneously the second link that is retained by the second joint shaft begins to rotate because the first joint shaft continues to be driven and rotated and it is connected with the second joint shaft by the belt. At 2nd phase, the second link of finger rotates until it makes a contact with the object and receives contact reaction force from it When reaction torque affects GaeaDrive® installed in the second joint mechanism and the reaction torque exceeds the adjusted torque of it, GaeaDrive® in the second joint mechanism occurs gliding between the link and its driving shaft and the second link stops to rotate keeping contact force at the adjusted value and maintaining a contact with the object just as the same as the first link motion.

Finally at 3rd phase, the third link contacts the object as the same manner as other links and articulated fingers makes envelope grasp mechanically keeping the fixed contact forces working toward object.

The friction torque set by GaeaDrive® installed in each joint mechanism regulates the contact force between each link of the finger and the object to be handled while the mechanical hand keeps an envelope grasp.



(a) 3-points contact (b) 2-points contact (c) 1-point contact

Figure8 Classification of grasp configuration

3. GRASP CONFIGURATION

The rotation is possible only for the direction which bends the finger inside for each link, because the mechanical stoppers have been attached at second joint and third joint. Therefore, three kinds of grasp configurations are possible for the developed mechanical hand according to the relative position between object and hand in the initial phase of the grasp motion.

Figure8 shows classification of grasp configuration. Figure8(a) is the case in which all links contact the object and two-fingered hand envelope the object firmly. In the developed hand with 3 DOF, the number of contact points by one finger is 3. Figure8(b) is the case in which two links from the finger tip contact the object and the number of contact points is 2. Figure8(c) is the case in which hand pinches the object. In these cases, grasp configuration with 3-points contact (a) seems to be the most stable and suitable.

On the assumption of a grasp of the cylindrical object by 2 fingers with 3 joints in two-dimensional plane, the condition for realizing a suitable envelope grasp is calculated [11]. Diameter of the object : d, distance between object and palm plate : h and mounting distance of two fingers : w are made dimensionless by finger overall length : p as follows.

$$D=d/p, \qquad H=h/p, \qquad W=w/p$$

Figure9 shows the region of diameter of object D and distance between object and palm plate H in W=0.5 which can realize a suitable envelope grasp where all links of the finger make contact with the object firmly. The suitable envelope is possible within the dimensionless diameter of the object : D=1.4 from D=0.3. In other words, the developed mechanical hand is able to grasp the various sized object of the wide range from 0.3 times of the finger length to 1.4 times of it.

That a stable grasp of the object of which the size differs widely is possible in one mechanism is the remarkable merit which none of the conventional mechanical gripper has.

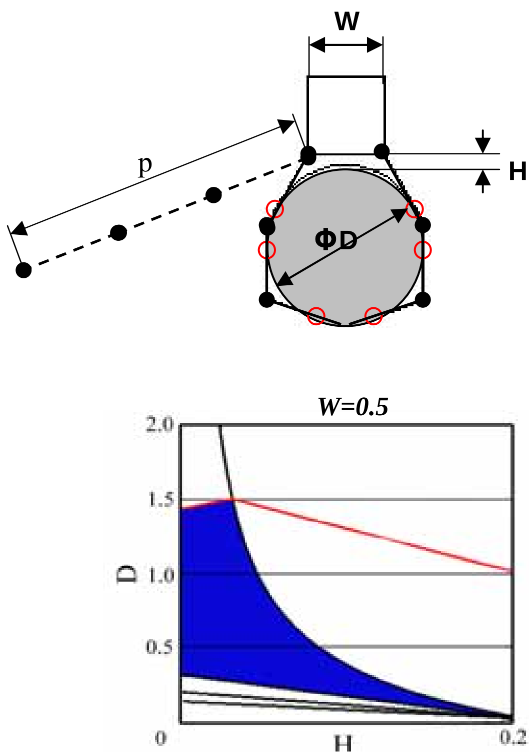


Figure9 Region of suitable grasp configuration (W=0.5)

4. EXPERIMENTS

Figure10 shows a measurement result of joint torque in the grasp condition. Experimental results prove that the joint torque is retained stably at constant magnitude with the good accuracy. It means that contact force between finger link and object could be kept constant during the grasp. Pressing force P which works friction generation mechanism GaeaDrive® is changed in the experiment and joint torque increases in accordance with the pressing force P. These results prove that the joint torque in the grasping could be tuned by adjusting the pressing force P of GaeaDrive® which is installed in the joint mechanism and the contact force to the object could be adjustable .

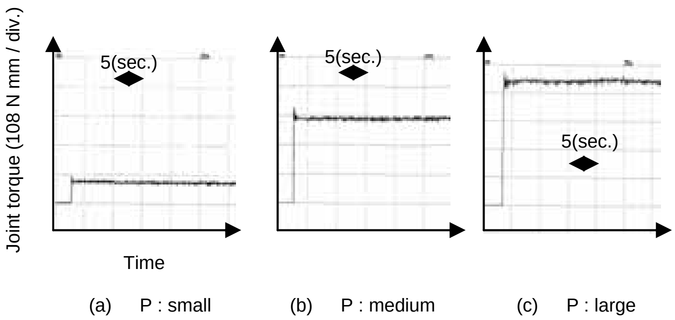
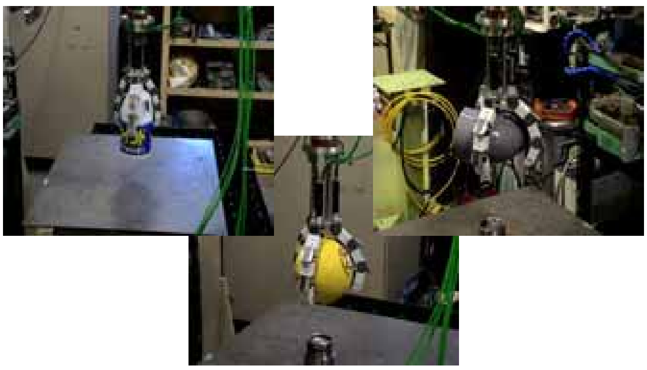
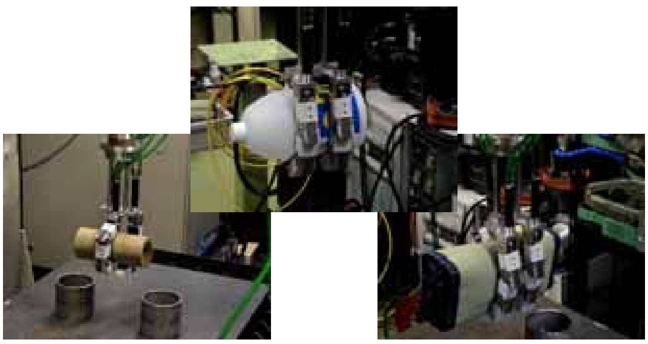


Figure10 Joint torque adjusted by GaeaDrive®

Figure11 shows experimental grasps of various shaped or sized parts. The developed mechanical hand forms envelop grasp for different parts successfully and handle them firmly.



(a) Spherically shaped parts



(b) cylindrically shaped parts

Figure11 Experiments of envelope grasp

5. CONCLUSION

A multi-fingered mechanical hand with envelope grasp capability for various shaped or sized parts has been developed and its usefulness is confirmed through experiments.

Remarkable features of the newly designed hand is accomplished by introducing compact torque limiter device GaeaDrive® to the joint mechanism.

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