Educational-industrial complex development
of an anthropomorphic robot hand ‘Gifu hand’

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Keywords: Robot; hand; multi-finger; force sensor; tactile sensor; educational-industrial
complex; humanoid.

1. INTRODUCTION

It is expected that forthcoming humanoid robots will execute various complicated
tasks via communication with a human user. The humanoid robots will be equipped
with anthropomorphic multi-fingered hands very like the human hand. We call this a
humanoid hand robot. Humanoid hand robots will eventually supplant human labor
in the execution of intricate and dangerous tasks in areas such as manufacturing,
space, the seabed, etc.
Our group, which consists of six members from small manufacturing companies
in the Gifu prefecture, Japan and one member from Gifu University, has been
developing the Gifu hand, a five-fingered hand driven by built-in servomotors as
an educational-industrial complex development since 1996. We aimed to develop
the robot hand which is used as the standard platform of the study on dexterous
grasping and manipulation of objects.

2. ROBOT HAND DESIGN

An overview of the developed anthropomorphic right and left version of the Gifu
hand  is shown in Fig. 1. The right and left hands are designed symmetrically, and

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**Figure 1.** Developed Gifu hand

**Figure 2.** Overview of the finger with a 6-axes force sensor
Figure 3. Mechanism of the thumb

have a thumb and four fingers. An overview of the finger with a 6-axes force sensor at the finger-tip is shown in Fig. 2. The design mechanism of the thumb is shown in Fig. 3. Servomotors and joints are numbered from the palm to the finger-tip. The thumb has four joints with 4 d.o.f. and the fingers have four joints with 3 d.o.f. Movement of the first joint of the thumb and of the fingers allows intortion and extortion, and that of the second joint to fourth joint allows anteflexion and retroflexion. The main difference between the thumb and the fingers is that the fourth joint of the fingers is actuated by the third servomotor through a planar four-bar linkage mechanism. Thus, the Gifu hand has 20 joints with 16 d.o.f. Each servomotor (Maxson DC motor; Interelectric AG) has a magnetic encoder with 16 pulses per revolution. Table 1 summarizes the characteristics of the Gifu hand.

The hand is designed to be compact, lightweight and anthropomorphic in terms of geometry and size, such that it performs grasping and manipulations like the human hand. The design concept is as follows.

2.1. Size

It is desirable for the robot hand to resemble the human hand in size and geometry for purposes of skillful manipulation. The robot hand was designed to be similar to a relatively large human hand, and has a thumb and four fingers.

2.2. Number of joints and number of d.o.f.

The thumb and finger of the human hand can be modeled as a serial link mechanism with four joints. All joints of the thumb move independently. The finger also has four joints, but it has only 3 d.o.f. because its fourth joint engages with the third joint
almost linearly. The thumb is more dexterous and powerful than the fingers. The first joint and the second joint of each finger cross almost orthogonally at one point. The number of joints and number of d.o.f. of the robot hand were designed to mimic those of the human hand. The thumb is actuated by four servomotors and the fingers actuated by three servomotors. The fourth joint of the fingers are driven by the third servomotor through a planar four-bar linkage mechanism as shown in Fig. 4. Figure 5 shows relations between the third and fourth joint angles of the human and the Gifu hand. The planar four-bar linkage mechanism is a non-linear transmission mechanism; however, the fourth joint angle of robot finger engages with the third joint almost linearly like a human’s finger. Moreover, the hand was designed such that the first joint and the second joint of each finger cross orthogonally at one point by means of an asymmetrical differential gear.
Table 1.
Specifications of the Gifu hand

<table>
<thead>
<tr>
<th></th>
<th>finger</th>
<th>thumb</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.20 (kgf)</td>
<td>0.25 (kgf)</td>
<td>1.4 (kgf)</td>
</tr>
<tr>
<td>Output force at the finger-tip</td>
<td>8.8 (N)</td>
<td>1.1 (N)</td>
<td></td>
</tr>
<tr>
<td>Gear ratio of the thumb</td>
<td>1st joint 549.56:1</td>
<td>2nd joint 384.69:1</td>
<td>3rd joint 73.43:1</td>
</tr>
<tr>
<td>Band width of the thumb</td>
<td>1st joint 13.0 (Hz)</td>
<td>2nd joint 11.1 (Hz)</td>
<td>3rd joint 7.0 (Hz)</td>
</tr>
</tbody>
</table>

2.3. Opposability of the thumb

The thumb of the human hand can move in opposition to the fingers. Dexterity of the human hand in object manipulation is caused by this opposability. The robot hand was designed such that it has an opposable thumb.

2.4. Built-in servomotor

For easy attachment to the robot arm, the robot hand was designed such that all joints are driven by built-in DC servomotors with a rotary encoder. To produce a high stiffness hand, the transmission system was created by using high stiffness gears such as a satellite gear and a face gear instead of low stiffness gears such as a harmonic drive gear, and without using tendon cable.

2.5. Unit design

Easy maintenance and easy manufacture of the robot hand are very important, so each joint was designed as a module and each finger was designed as a unit. Due to the unit design of the finger, hands having from two to five fingers are easily made.

2.6. For sensor

Each finger of the robot hand was designed to be equipped with a 6-axes force sensor (nano sensor made by BL Autotec Co.) for compliant pinching.
2.7. Distributed tactile sensor

There are many sense organs in the human hand. These permit the human hand to manipulate an object dexterously. It is expected that more tactile sensors enable more dexterous manipulations. The robot hand was designed to be mounted with a developed distributed tactile sensor with 624 detecting points. Figure 6 shows an overview of the 6 d.o.f. robot arm (VS6354B; Denso Co.) and the Gifu hand that is equipped with the 6-axes force sensor at each finger-tip and the developed tactile sensor. The tactile sensor has a grid pattern electrode and uses conductive ink in which the electric resistance changes in proportion to the pressure on the top and bottom of a thin film. Numbers of detecting points on the palm, the thumb and the finger are 312, 72 and 60, respectively, and the total number of measurement points is 624. Electrode width is 2 mm, column pitch is 4 mm and row pitch is 6 mm. Maximum load is about $7.4 \times 10^{-4}$ N/m$^2$, resolution of measurement is 8 bits and sampling cycle is 10 ms/flare.

Output patterns of the tactile sensor while the Gifu hand is holding a cylindrical object 95 mm in diameter are shown in Fig. 7. It is clear that the output pattern depends on the shape of the object. These results show that the Gifu hand with the distributed tactile sensor has a high potential for dexterous grasping and manipulation.

Figure 6. Gifu hand with five 6-axes force sensors and the distributed tactile sensor.
Figure 7. Output patterns of tactile sensor at grasping cylindrical object. (a) Overview grasping a cylindrical object. (b) Output patterns of a tactile sensor.

3. CONCLUSIONS

We have presented the design concept and the mechanism features of the Gifu hand, which is designed to be used as a standard anthropomorphic robot hand. The Gifu hand is actuated by built-in servomotors, distributed tactile sensors can be attached to its surface and it is equipped with a 6-axes force sensor at each fingertip. The mobile space and geometrical size of the fingers are similar to those of the fingers on the human hand. The Gifu hand has a much higher number of sensors and higher response than any previously developed robot hand, and can move more quickly than the human hand. We consider that the Gifu hand is useful as a research tool for dexterous robot manipulation using both force and tactile sensing.