Development of POSTEC HAND-V Index Finger Module

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Abstract: We define that the end effector is the device which interact environment or objects with contact to execute tasks. Up to now, many researchers developed anthropomorphic robotic hands as end effectors. In this paper, we will discuss a problem on the development of a human-scale and motor-driven anthropomorphic robot hand. In this paper, design concept, actuator and transmission, kinematic design and sensing device are presented. By imitating the physiology of human hands, we devised new metacarpalphalangeal joint and interphalangeal joint suitable for human-size robot hands

Keywords: robot hand, end effector

1. INTRODUCTION

In robotics we define the end-effector as a device which performs tasks in mechanical contact with external environment or objects, especially end-effector which has serial or parallel multiple limb is called as robotic hand, and we call manipulation of the object by robot hand as dextrous motion. In most applications, 1 DOF end-effector, gripper is used for only picking/placing.

Robotic hand research is rooted from prosthetic arm and hand. Therefore it is natural that previous researchers made the imitation of human hand as a mark of a research on robotic hand.

Some researchers suggested the interesting kinematic design of Robotic hand [1–3]. Except of micro robotic hands, most of design are imitated or derived from human hand.

Anthropomorphic robot hands have a lot of advantages. Because a human hand possess all functionality we must design, So We can achieve our design objectives through just reproduction. This bio-mimic research method is useful to control robot hands, also [11].

Another reason of anthropomorphic robot hands is applications of robot hands, for example, human-robot cooperation, humanoid, tele-operation in extreme environment, service robots. Application of robot get near to works for and nearby human.

To develop robot hands and to apply it to practical robot is very tough job, because we need powerful actuators and elaborate sensors and enough tiny robot hands.

One solution is tendon-driven actuator. Utah/MIT hand [13] is driven by pneumatic actuators which is out of hands. Pneumatic actuators pull up tendons which roll the pulley in a finger joint. Most of robot hands in practical application are tendon-driven system. Disadvantage of tendon-drive is un-precision and maintenance. Friction force of tendon sheath or router grow as more as the length of tendon. General tendon length is 10 times over than robot hand. Also assembly and maintenance is a hard job. So motor-drive actuator [12] is suggested. Motor-driven actuator is enough small to be packaged in robot hands but have low power. But motor technology is being brought up gradually to be sufficient to robot hands.

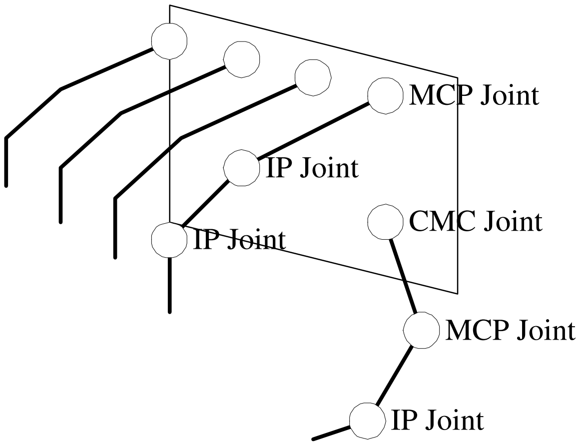


Fig. 1. Human Hand Model

Hardware development is presented in Sections 2. ∼ 4, in Section 2. we discuss on the actuator and transmission, and construction of joints. In Section 3, Fingertip force sensor developments is presented. Section 4. describes on motor driver.

2. Joint, Actuator Transmission

2.1. Finger design

Postech Hand V is integrated to anthropomorphic type. Fig. 1 represent human hand model. IP(Interphalangeal) joint of Index finger is the revolute joint. MCP(Metacarpaphalangeal) joint is a universal joint. This is well-known human hand property. But MCP of Thumb has only one degree of freedom. CMC(carpometacarpal) joint motion can be described two revolute joint which is connected a short link.

We designed index finger length ratio to 2:3:5, this ratio is the Fibonacci sequence which is frequently observed link ratios including human finger ratio.

A frame work is constructed to the forms of Proximal, Middle, Distal shells which are assembled with each motor drive IP joint motor and sensor wires pass through Shells.

2.2. Actuator

Many kinds of actuator are installed to develop robot hands for reason of size and power requirement. Even now we don't have proper actuator.

Postech Hand V has 4 DC Motors, DC motors are cheap, easy to implement. One of our object is human-scale size and there is small size of DC motors in market. DC motor is proper in miniature robot until now. We'll show the specification of Motor/Encoder/Gear of P-V index finger in Table 1.

Table 1. Motors

	Motor	gear	resolution
PIP	1516SR012SR	15/8(262:1)	512 bit/rev
MIP	1524SR012SR	16/8(262:1)	512 bit/rev
MCP	1724SR012SR	16/7(246:1)	512 bit/rev
MCP	Futaba S9550	RC Servo	potentiometer

2.3. Development of IP joint

Developing robot hands using DC motors, we have severe problem at gears and transmissions. Generally DC motors is operated with high speed and low torque and have relatively long length through a rotation axis , Therefore DC Motor needs transmission and gear box to increase torque and change rotation axis. To solve this problems previous developers suggested tendon-sheath transmission [4] or polymer transmisson [5] or combination Screw/Worm gear with tendon and slider-crank mechanism [6, 7].

In this case, we use bevel/meter gears to usual industrial robots, and we will have too large joint for human-size robot hand. So we developed Twisted 8-shaped Tendon transmission to miniaturize robot hand using tendon instead of bevel gear tooth.

The twisted 8-shaped tendon joint is composed of two bevel pulley, tendon, bolts/washer which fix tendon to pulley. In Fig. 2 tendon is wounded on groove of pulley. One pulley is connected to motor axis, the other pulley to the joint.

Two bevel pulleys make contact each other for tendon not to break away. tendon is wounded to pulleys through groove and fixed with bolt and washer. The diameter of wire should be decided by experiments because thin wire may break away from groove or be worn by rubbing edge of the pulley, and heavy one is not put in the groove and disturb rotation. We used 9-strip plastic coating stainless steel wire of 0.42mm diameter.

Construction of twisted 8-shaped tendon joint is simple, small, light weight but hard to assemble. Without expert fabrication, backlash is.

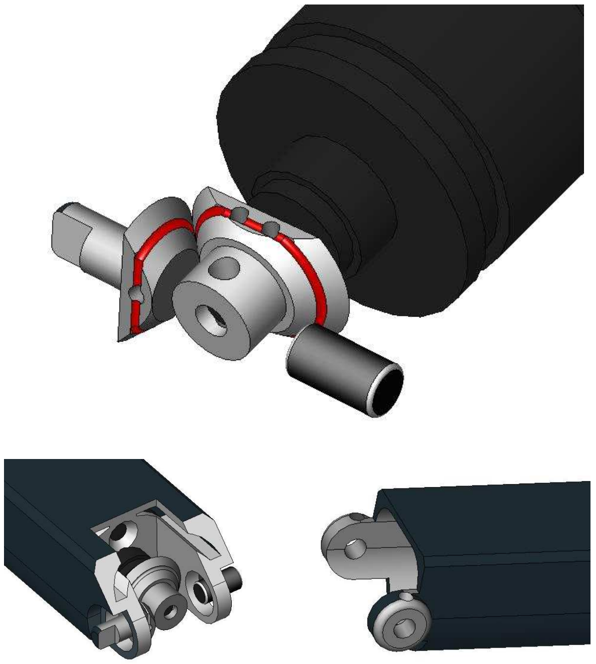


Fig. 2. Twisted 8-shaped tendon joint

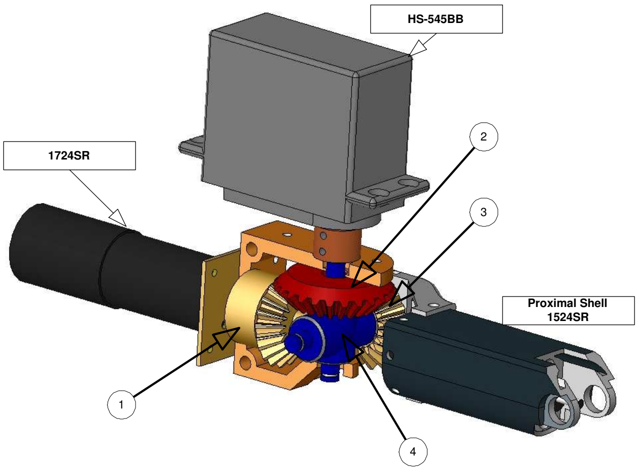


Fig. 3. Composition of MCP joint

2.4. Development of MCP joint

MCP joint and its property is known by the problem in biomechanics [8]. H.R.Choi [9], J.Butterfass [10] developed universal joint driving mechanism which is equivalent to MCP joint.

MCP joint of new developed Postech hand-V Index Finger is composed of three bevel gear, cross axis and gearbox. Fig. 3 describes the assembly of MCP joint. The first gear with 1724SR Motor has 20 tooth, the second 25 tooth and the third 20 tooth of module 1, helical type. The second gear is assembled with the vertical axis of cross axis and the third gear horizontal axis with bearing.

2.4.1 Flexion/extension operation

The torque of 1724SR Motor drives the first gear. This torque is transferred to the third gear through the second gear. The second and the third gear rotates for vertical and horizontal axis. For flexion/extension motion, cross axis does not move. The S9550 motor which is connected vertical axis of cross axis, positions the cross axis. If S9550 Motor did

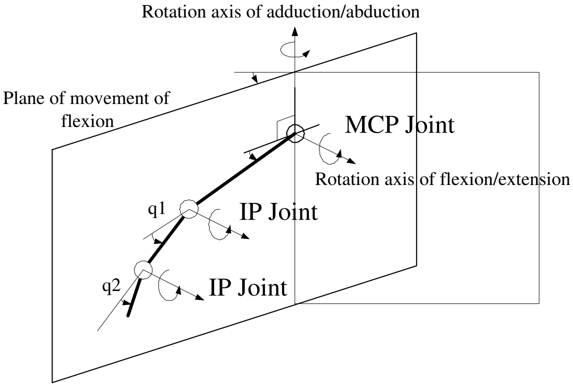


Fig. 4. rotation axis of finger

not generate the counter torque, abduction/adduction motion also is occurred. The third gear is fixed to finger frame, therefore the index finger moves flexion/extension motion.

2.4.2 Adduction/abduction operation

Adduction/abduction motion is generated by S9550 motor. S9550 motor is connected to the vertical axis of the cross axis. In adduction/abduction motion, the second gear also rotates. Therefore 1724SR motor must compensates it not to remove flexion/extension.

2.4.3 MCP Joint Kinematics

We can obtain kinematics geometrically.

$$\begin{bmatrix}\phi\\ \psi\end{bmatrix} = \begin{pmatrix}0 & 1\\ 1 & \frac{r_2}{r_1}\end{pmatrix}\begin{bmatrix}\theta_{m_1}\\ \theta_{m_2}\end{bmatrix} \tag{1}$$

where, ϕ is flexion/extension angle,ψ adduction/abduction, r_1 the radius of no.1,3 bevel gear and r_2 no.2(Fig.4).

2.4.4 MCP Joint Dynamics

Dynamics of Voltage Amplifier and motor is

$$V_1(s)\frac{1}{L_1 s + R_1}k_1 k_2 = \tau_{q_1} \tag{2}$$

$$V_2(s)\frac{1}{L_2 s + R_2}k_3 k_4 = \tau_{q_2}, \tag{3}$$

where L is inductance of motor,R resistance $k1, k3$ torque constant, and $k2, k4$ gear ratio.

We assume the friction of motor is relatively small and obtain dynamic equations from free body diagram.

$$(V_1(s)\frac{1}{L_1 s + R_1}k_1 k_2 \frac{1}{r_1} - F_1) = J_{g_1}\ddot{\theta}_{g_1} \tag{4}$$

$$F_1 r_2 + F_2 r_2 = J_{g_2}\ddot{\theta}_{g_2} \tag{5}$$

$$(V_2(s)\frac{1}{L_2 s + R_2}k_3 k_4 \frac{1}{r_2} - F_3) = J_{g_1}\ddot{\theta}_{g_1} \tag{6}$$

$$F_2 r_1 = J_\psi \ddot{\psi} \tag{7}$$

$$F_2 r_2 + F_3 r_2 = J_\phi \ddot{\phi} \tag{8}$$

$$\theta_{g_2} = \frac{r_1}{r_2}\theta_{g_1} \tag{9}$$

$$r_2\theta_{g_2} - r_1\psi = r_2\phi \tag{10}$$

Table 2. rotating inertia of P-V index finger

parameter	J_{g_1}	J_{g_2}	J_{m_3}	J_ψ	J_ϕ
gmm^2	798.9	1185.0	169.64	80100	80862

Table 3. 090SC : Side-tab gage with extremely narrow grid for use near abutments

Dimensions	in	mm
Gage Length	0.090	2.29
Overall Length	0.120	3.05
Grid Width	0.010	0.25
Overall Width	0.060	1.52
Matrix Length	0.18	4.6
Matrix Width	0.14	3.6

Gage Designation (1)	Resistance (2)	Options
EA-XX-090SC-120	120 0.2%	W , E , L , LE , P
WA-XX-090SC-120	120 0.4%	W *
SA-XX-090SC-120	120 0.4%	

Without backlash between bevel gears, we can arrange equations into more compact form.

$$V_1(s)\tfrac{1}{L_1 s + R_1}k_1 k_2 \tfrac{1}{r_1} = \tag{11}$$
$$(J_{g_1}\tfrac{r_2}{r_1} + J_{g_2})s^2\phi(s) + (J_\psi \tfrac{r_2}{r_1} + J_{g_1} - J_{g_2}\tfrac{r_1}{r_2})s^2\psi(s)$$

$$V_2(s)\tfrac{1}{L_2 s + R_2}k_3 k_4 = \tag{12}$$
$$(J_\phi + J_{m_3})s^2\phi(s) + (\tfrac{r_2}{f_1}J_\psi)s^2\psi(s)$$

Substituting CAD data Table. 2, equations become more simple,because J_ψ, J_ϕ is larger than $J_{g_1}, J_{g_2}, J_{m_3}$ over $\boldsymbol{O}(2)$.

$$V_1(s)\frac{1}{L_1 s + R_1}k_1 k_2 \frac{r_2}{r_1} = J_\psi \frac{r_2}{r_1}s^2\psi(s) \tag{13}$$

$$V_2(s)\frac{1}{L_2 s + R_2}k_3 k_4 = J_\phi s^2\phi(s) + \frac{r_2}{r_1}J_\psi s^2\psi(s) \tag{14}$$

Rewriting on the torque.

$$\tau_1 = J_\psi s^2\psi(s) \tag{15}$$

$$\tau_2 = J_\phi s^2\phi(s) + \frac{r_2}{r_1}J_\psi s^2\psi(s) \tag{16}$$

$$\begin{bmatrix}M_\phi\\ M_\psi\end{bmatrix} = \begin{pmatrix}-\frac{r_2}{r_1} & 1\\ 1 & 0\end{pmatrix}\begin{bmatrix}\tau_1\\ \tau_2\end{bmatrix} \tag{17}$$

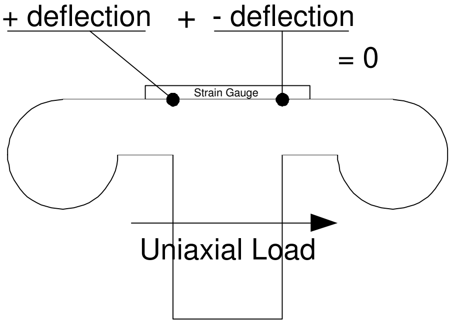
3. Fingertip Force Sensor

In order to manipulate object, we should get the information of the contact wrench between the object and the hand.

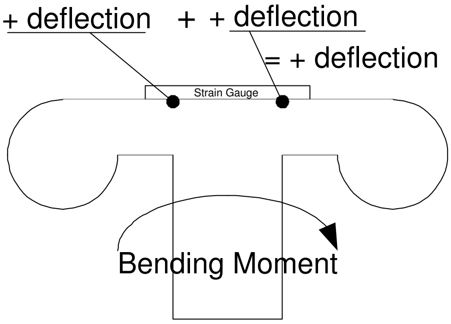
we designed the fingertip force sensor which can measure 6 dimensional force/moment with 6 strain gauges-090SC and 062DW of Micro-Measurements Inc.

Strain gauges are used to measure loads applied to the beam. To measure bending moments, uniaxial load and torque simultaneously, we needs too many strain gauges to glue on the surface of the small force-sensitive structure. But the deflections of the structure in Fig. 5 is measurable with a

Fig. 5. principle to measure bending moment deflection reducing axial load deflection



(a) Axial load deflection



(b) Bending moment deflection

few number of strain gauges. If axial load and bending moment is applied to the center-locked beam in Fig. 5(a), the deflection of axial load is much smaller than the usual beam and only bending moment is prior to deflect the beam in Fig. 5(b). We made fingertip force sensor out of 6 structure of Fig. 3.

There are bending moment stress and axial load stress in No.1 ∼ No.6 beams. But No.1,2,3 tend not to elongate or compress because of the center triangular structure. The most part of their deflection are bending.

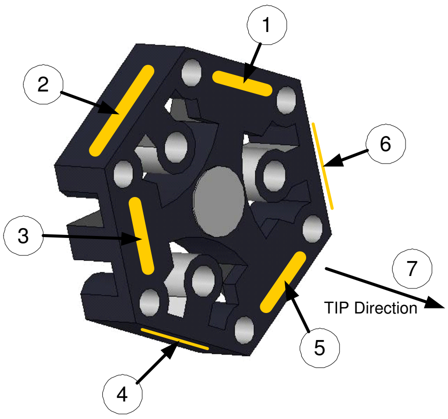
We used FEM Analysis to understand the relation between forces and strain gauge signal. In the Table. 4, × means deflecting ratio is very low or 0, + elongation, − compression. Torque about tip direction is measured by No.7.

Table 4. The relation between Forces and deflection

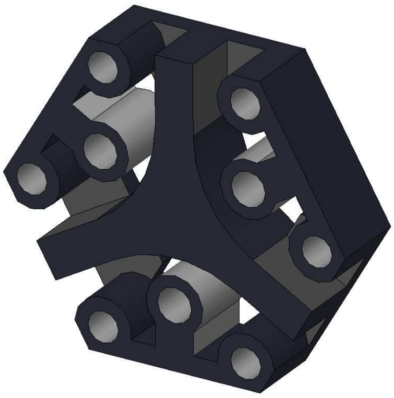
	1	2	3	4	5	6
F_x	×	×	×	-	×	+
F_y	×	×	×	-	+	×
F_z	-	-	-	×	×	×
M_x	-	+	+	×	+	×
M_y	×	-	+	-	×	+
M_z	×	×	×	×	×	×

4. Motor Drivers

We fabricated 2 kinds of motor drivers. One is current(torque) driver, the other is voltage(velocity). We fabricate it using OP Amp with current limiter two of 0.8A, 0.45A, 0.2A. Fig. 7 is the picture and circuit of motor drivers.

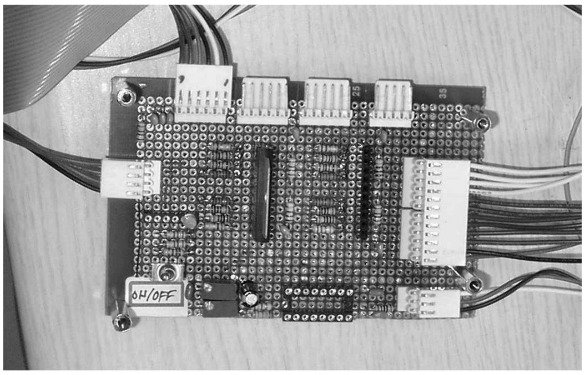


(a) front view

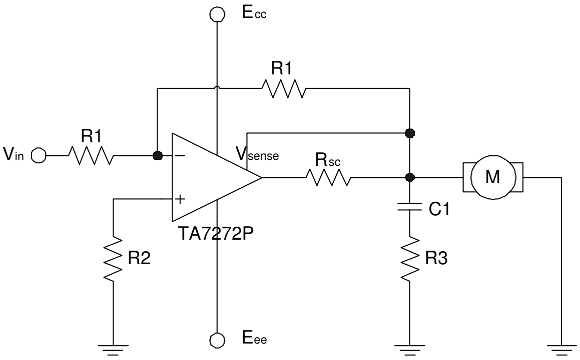


(b) backside view

Fig. 6. The principle of force sensor unit



(a) picture of motor amp



(b) circuit diagram of motor amp

Fig. 7. Voltage Amplifier for velocity servo

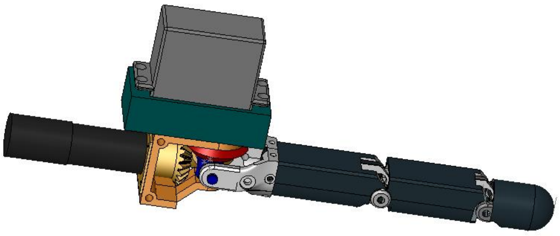


Fig. 8. Postech Hand V Index Finger module

5. Concluding Remarks

The index module of Postech Hand V is designed toward human-size motor-driven robot hand. The finger length is 135 mm, total length 215 mm, weight 350g, nearly same as the human-size. We develop two middle and thumb of different size and work space and compose Postech Hand V. Fig. 8 is developed index finger.

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