Optimize Position to Place Joint of a Finger in the Slave Hand of a Novel Master-Slave System

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Received: June 07, 2017; Accepted: May 25, 2018

Abstract

Nowadays, the teelopration system in general, the master-slave (MS) hand in particular has been using popularly in many technology and manufacturing sectors. It easily and safely supports people in many risk and hard working jobs. Besides, in the medical field the MS system is also been using to tele-operate for the patients. In this paper, the mechanism design and the optimization for the index finger's joint position were discussed in a novel suggested MS hand system. The finger was driven by a servo motor through the nut-screw system and the four-bar mechanisms. The position, distances between joints of the finger were determined in advance by the avarage values of the adult people. The positon of rotational joints of the four-bar mechanisms was optimized in order to receive the minimum consumption power of the actuator. The simulation results shows that after optimizing the difference of power consumption between the maximum and minimum values is 6.27 times. And we found out the minimum position.

Keywords: Teleoperation, master-slave hand, optimization mechanism, four-bar mechanism.

1. Introduction

Teleoperation system permits the mission of human at a distance, and it was first introduced in 1950s, when Goertz built the first mechanical MS for manipulating radioactive materials [1].

Teleoperation is being used in surgery, advanced manufacturing, and education. In surgery, teleoperation is exemplified in minimally invasive surgical robots [2-4], which enhance a surgeon's accuracy, dexterity, and visualization [5]. In advanced manufacturing, teleoperation allows human workers and robots to work intelligently together to combine human perceptual and problem-solving capabilities with the power and accuracy of machines [6]. In education, teleoperation enhances remote-learning by enabling students to access a robotics laboratory via the internet [7-10].

A teleoperation interface consists of master and slave devices. The master device may be a keyboard or joystick [11], or haptic devices, such as data gloves and exoskeleton devices [12]. The slave device may be a physical robot or a computer-generated representation of robots in a virtual world [8,10].

In this research we suggested a new slave mechanism. In this mechanism we used four-bar structure to transfer the motion to phalanxes in each finger. Thus, each finger is driven by only one actuator. In the four-bar linkage, there is one driven link that attack force to rotate the joint. The distance between joint of phalanxes is decided by the medium of mature people. As a result, the location of two joint's driven link need to be found. In this study, we also suggested a method to find the optimal position of these joint.

The paper is organized as follows. It first describes suggested mechanism of slave system. After proposing the structure, the optimization requirement for the system is debated. This requirement is to define the range of variable to locate the position of the joints. Finally, after receiving the ranges, these parameters were imputed to the ADAMS software to optimize the objective function.

2. Methodology

2.1 Proposing slave side mechanism of the teleoperation

There are some requirements for the system: the system has the ability to grasp tools, things, and perform some auxiliary movements. The movement of the slave hand should be smooth, and it has dimension to be relative close to human hand. The system is light weight and low cost.

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From all of above goal: we are developing a new slave mechanism. This system has three fingers of thumb, index and middle finger. The reason that we only chose these fingers is that they are most important fingers during grasping things. About the degree of freedom, the system has 4 DoF(s). Each index and middle have 1 DoF and the thumb one has 2 DoFs. The movements of the thumb include flexion, extension, abduction and adduction. Meanwhile, the movements of the fingers are flexion and extension. The size of the slave hand was determined based on the medium anthropomorphic hand size of mature people as the Table 1.

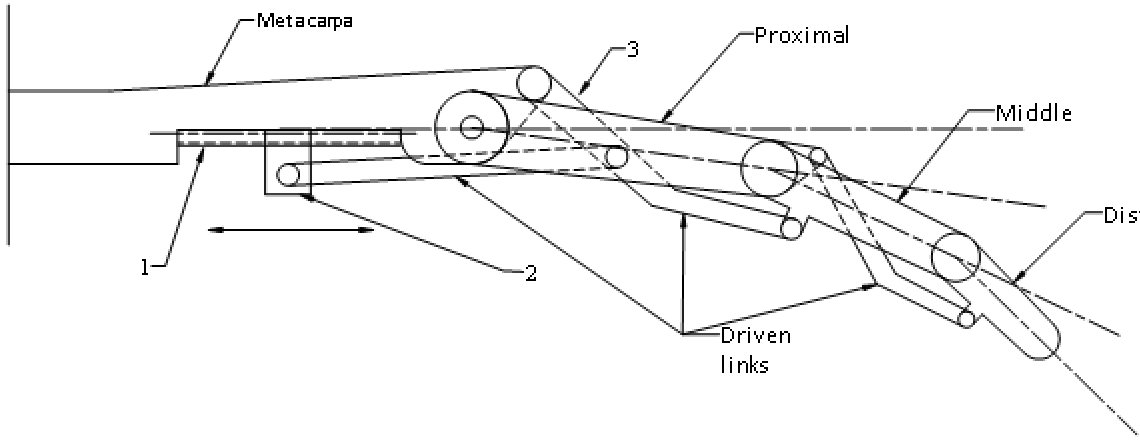
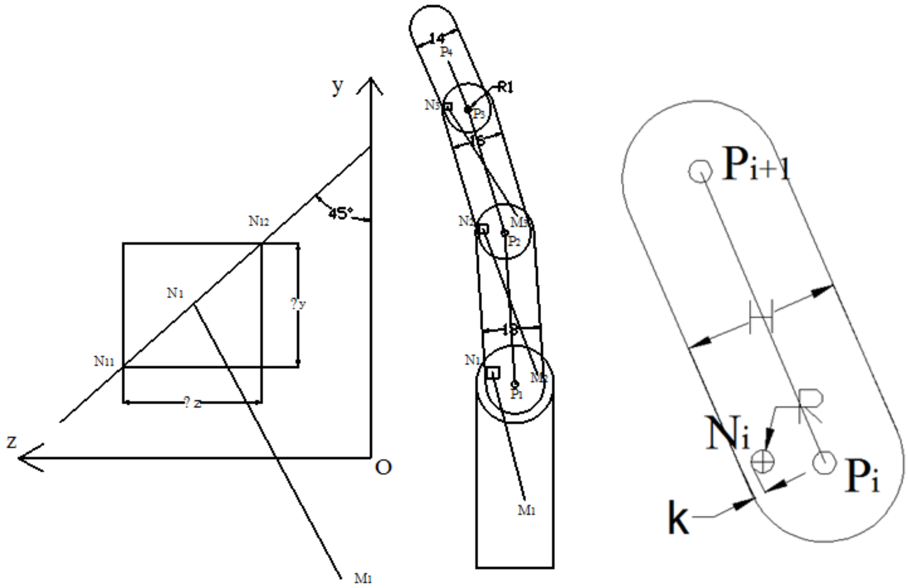


Fig. 1. Proposed mechanism for index and middle fingers.



a) Bouldary model b) Phalanx model

Fig. 2. Model to find boundary of joints.

Table 1. Fingers' dimensions of the slave hand.

Finger	Metacarpals length	Proximal phalanx	Middle phalanx	Distal phalanx
Thumb	43	38		30.5
Index	76,2	42,5	35,4	30,3
Middle	76,2	48,6	35,4	30,3

In order to actuate for each DoF, we used one DC Servomotor and Screw/nut mechanism as in the Figure 1. When the screw 1 is rotated it makes nut 2 move forward or backward. By using two four-bar linkages as the figure, the phalanxes of finger were moved.

In each of four-bar mechanism, size of each phalanx was decided as in Table 1. The question here is how we can define the position of driven links.

The calculation model is described in the Figure 2. The reasonable positions of driven links should make the power consumption minimum. This power consumption is calculated by:

$$P=F.V \quad (1)$$

Where: P is power consumption of the actuator. V is velocity of the nut. In this case, the nut's speed was assumed to be constant. F is driven force from the crew to the nut. To find out the minimum power consumption, the location of driven links must be optimized in order to receive the minimum driven force F.

2.2 Possible boundary of joints in each driven link

Based on the model shown in the Figure 2, in the Oyz plane we consider the driven bars M_1N_1, M_2N_2, M_3N_3. The points P_1, P_2, P_3 are the positions of the hinged joints between the phalanxes. In 6 points of driven bars, we fixed the points Mi (i = 1 ÷ 3) based on the farthest position on the bottom, right from the points Pi (i = 1 ÷ 3). Therefore, we must find the position of N_i points to get minimum force of F.

Table 2. Initial position of points.

Points	Y	Z
M1	22,45	7,5
N1	60,75	14,66
P1	50,5	7,5
M2	57,5	3,5
N2	100,54	18,66
P2	96,33	11,45
M3	100,86	9,33
N3	123,83	21,5
P3	121,74	17
P4	131,32	19,8

For simplicity, we set the value of $\Delta y = \Delta z$ as shown in the Figure, ie the operation area of Ni is the square of the top of the N_{ij} vertex (j = 1 ÷ 2). N_{ij} vertex must satisfy the following conditions:

1. The driven bar does not collide with the hinge P_i:

$$d(P_i; M_iN_i) \geq R+D_i/2 \quad (2)$$

2. The thickness of the phalanx is larger than the pin's radius:

$$k \geq R \Rightarrow d(P_i; M_iN_i) \leq (H_i/2 - 2R) \quad (3)$$

Where:

- d (P_i; M_iN_i) is distance from P_i to M_iN_i.

- R is hinge's radius (R=1)

- D_i is width of driven bar i. $D_{M1N1}=5$, $D_{M2N2}=4$, $D_{M3N3}=3$.

- H_i is width of phalanx. $H_1=18, H_2=16, H_3=14$.

The initial coordinates of Mi, Ni, and Pi points are available in the model given in the table 2.

a) First driven link

❖ Condition (2): $d(P_1, M_1N_{12}) \geq R+D_1/2=1+5/2=3,5$

Line equation though $N_{11}N_{12}$ (go though N_1 and incline with axes OY, OZ an angle of 45°

$$y+z-75,41=0 \quad (4)$$

(u,v) is coordinate of N_{12}. Then line equation M_1N_{12} is $\frac{y-u}{u-25,45} = \frac{z-v}{v-7,5}$

=> $\frac{|(v-7,5).50,5-(u-25,45).7,5+7,5u-25,45v|}{\sqrt{(v-7,5)^2+(u-25,45)^2}} = 3,5$ (5)

From (4) we have v=75,41-u

From 5 we have:

$$603u^2-82933u+2828972=0 \quad (6)$$

We get u=62,65=>v=12,76 . As a result, the coordination N_{12} =(62.65,12.67).

❖ Condition (3):

$d(N_1, P_1P_2) \leq (H_1/2-2R)=18/2-2=7$

Similarity as above calculation, (u,v) is coordinate of N_{11} belonged to the line function of:

$$y+z-75,41=0 \quad (7)$$

P_1P_2 line equation is

$$\frac{y-96,33}{96,33-50,5} = \frac{z-11,45}{11,45-7,5} \quad (8)$$

After calculation we found out: u=60,06 and v=15,35.

Then the coordination of N_{11} = (60.06 , 15.35).

b) Second and Third driven bar:

Similar steps were done for the remaining driven link. The results as following:

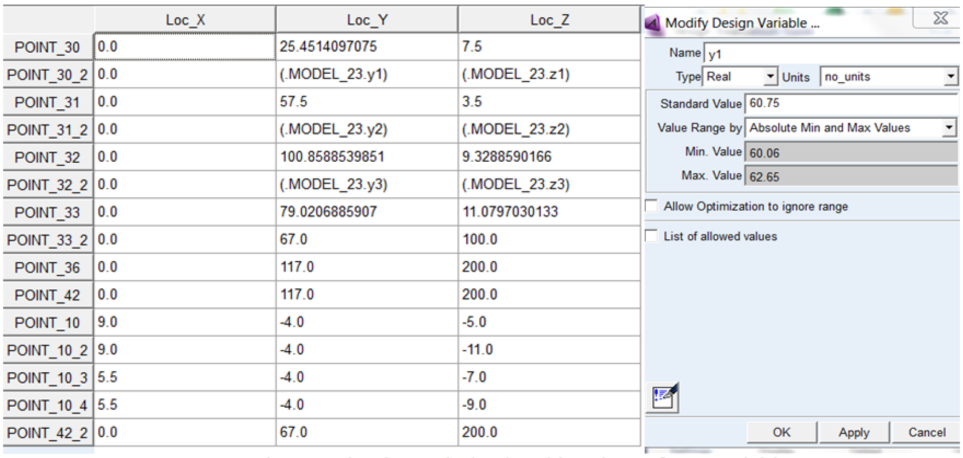
For 2nd driven bar: N_{22}=(102.81 , 16.39) and N_{21} = (100.67 , 18.53).

For 3rd driven bar: N_{32}= (124.3 , 21.03) and N_{31}=(122.79, 22.54).

In summary, we have the boundary of the position of the Ni points of the 3 driven bars as in the Table 3.

Table 3. Boundary of points N_i.

Point	y		z	
	min	max	min	max
N1	60,06	62,65	12,76	15,35
N2	100,67	102,81	16,39	18,53
N3	122,79	124,3	21,03	22,54



	Loc_X	Loc_Y	Loc_Z
POINT_30	0.0	25.4514097075	7.5
POINT_30_2	0.0	(.MODEL_23.y1)	(.MODEL_23.z1)
POINT_31	0.0	57.5	3.5
POINT_31_2	0.0	(.MODEL_23.y2)	(.MODEL_23.z2)
POINT_32	0.0	100.8588539851	9.3288590166
POINT_32_2	0.0	(.MODEL_23.y3)	(.MODEL_23.z3)
POINT_33	0.0	79.0206885907	11.0797030133
POINT_33_2	0.0	67.0	100.0
POINT_36	0.0	117.0	200.0
POINT_42	0.0	117.0	200.0
POINT_10	9.0	-4.0	-5.0
POINT_10_2	9.0	-4.0	-11.0
POINT_10_3	5.5	-4.0	-7.0
POINT_10_4	5.5	-4.0	-9.0
POINT_42_2	0.0	67.0	200.0

Fig.3. Points need to be optimized and boudary of one variable.

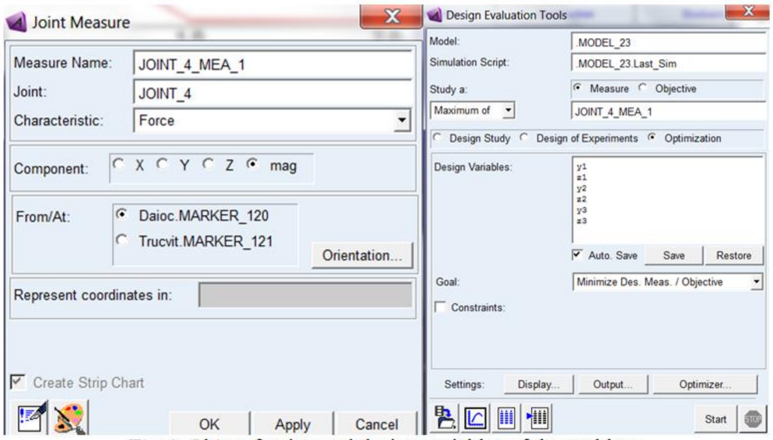
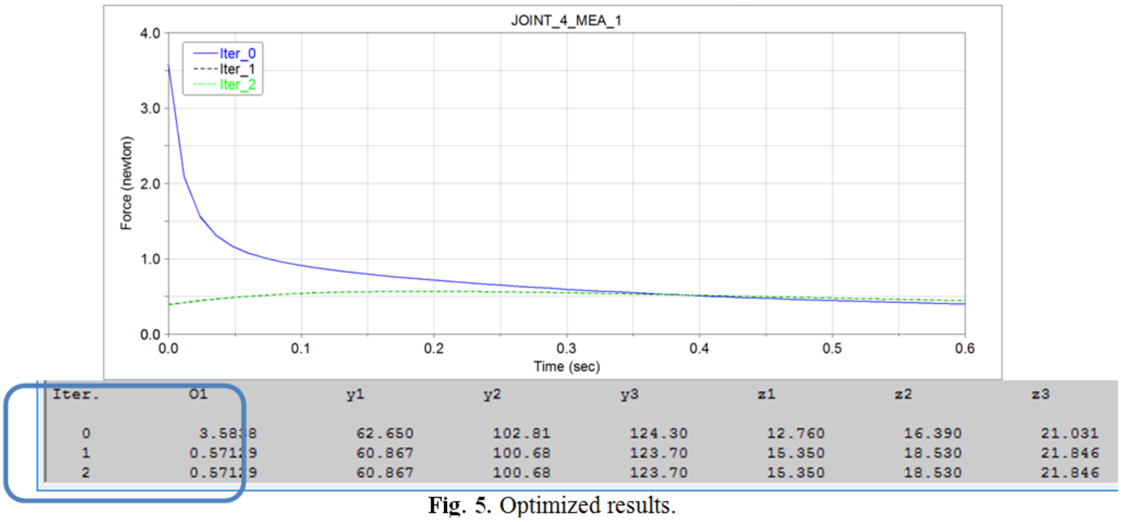


Fig.4. Object funtion and design variables of the problem.



Iter.	O1	y1	y2	y3	z1	z2	z3
0	3.5838	62.650	102.81	124.30	12.760	16.390	21.031
1	0.57129	60.867	100.68	123.70	15.350	18.530	21.846
2	0.57129	60.867	100.68	123.70	15.350	18.530	21.846

Fig. 5. Optimized results.

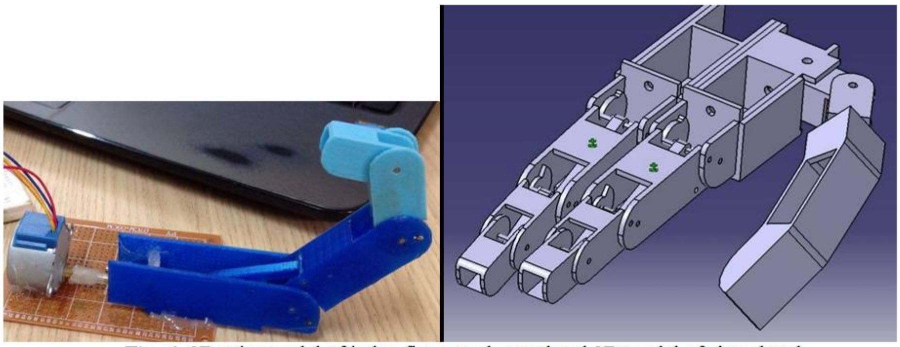


Fig. 6. 3D print model of index finger and completed 3D model of slave hand.

3. Optimized results

After finding the boundary of the points, these values are inputted as the variables in the optimization problem to find out the minimum attack force from screw to nut. The *Absolute Min and Max Values* option was used as shown in Figure 3. The objective function of the optimal problem is the minimum of the maximum value of the force acting on the nut. This value is the JOINT_4_MEA_1 force as shown in the Figure 4.

After setting parameters for the design variables, the value of the force JOINT_4_MEA_1 was optimized and found after 3 loops as shown in the Figure 5. According to the result, the minimum value of the force acting on the nut is 0.57129N corresponding to the variable y_1=60,867; y_2=100,68; y_3=123,7; z_1=15,35; z_2=18,53; z_3=21,846. The difference between the maximum and minimum values of the force acting on the nut is 6.27 times.

4. Conclusion

In this paper, a novel slave hand mechanism was proposed. The mechanism used the four-bar linkage to transfer the motion generated from actuator to the phalanxes of the finger. The dimension of each finger was received from the medium hand anthropomorphy of mature people. In order to optimize the suggested mechanism, the joints' position of the three driven bars was found out by using optimization tool in ADAMS software. The results exposed that when varying position of vertexes (joints) of driven links, the difference between the maximum and minimum values of the force acting on the nut is 6.27 times. It means the distinct between the maximum and minimum power consumption due to changing placed position of joints of links is 6,27 times. As a result, the joints' positions of link which has minimum power consumption is the best one.

This research is funded by the Hanoi University of Science and Technology (HUST) under project number T2016-PC-065

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