DESIGN OF THE LOW COST ANTHROPOMORPHIC GRIPPER FOR INDUSTRIAL ROBOTS

Marian Bolboe[1], Ionel Staretu[1]

[1]*Transilvania University of Brasov, Brasov, Romania, bolboe@yahoo.com, staretu@unitbv.ro.*

Abstract: *The gripping operations are particularly important in handling tasks and especially robotic assembly. The gripping of items with various shapes and configurations required the transition form te grippers with jaws to the anthropomorphic grippers with fingers. A significant number of such grippers were made and tested in the last few years, but no relatively simple, reliable and low priced solution was found. This made the multiplication of applications and their widespread use impossible. Based on this situation, this paper presents a structural and kinematic characteristics of an optimized new gripper with two finger. After the features of such a gripper were identified, a structural scheme was proposed and a CAD project was presented and a CAD simulation too.*

Keywords: *Robotics, Anthropomorphic grippers, Mechanism, Design, Functional simulation.*

1. Introduction

Researches in the field of anthropomorphic grippers have focused more on grippers with three, four and five fingers, for robots and prosthetics[1].

We mention here grippers with outstanding performances, such as presented in Figure 1: the Barrett gripper [2]; the DLR II [3]; the Shadow Hand [4], etc.

The performances of the existing anthropomorphic grippers are directly proportional to their complexity, whilst their price is directly related to their complexity (between 30.000 and 91.000 Euros). This paper’s purpose is to introduce a new, two-fingered, gripper, characterized by constructive simplicity and the capacity to grasp complex shaped objects.

This harmoniously combines simplicity and performance, with direct benefit in the price of such a gripper.

a

b

c

Figure 1: *Examples of actual anthropomorphic performing grippers.*

2. Structural Synthesis and Analysis

Source of inspiration for this anthropomorphic mechanism was the human hand, which is able to insure high gripping possibilities with only two fingers, as shown in Figure 2.

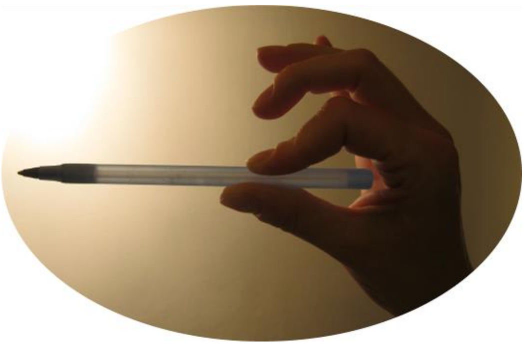


Figure 2: *Anthropomorphic gripping with two fingers.*

The anthropomorphic gripper is a new mechanism, with articulated bars, as shown in Figure 3. It is made up of two identical fingers, each with two phalanxes[5],[6].

The two-fingered anthropomorphic gripper, which is part of the experimental stand, is inspired from the human hand and its possibilities to grasp objects using two fingers.

The actuation of both fingers is achieved by using a single motor. The mobility of the mechanism is given by the equation no. 1 – "calculation of the mobility of the mechanism" or by the equation no. 1– "mobility calculation of plane mechanisms".

$$M=\sum f_i-3k=10-3\cdot 3=1,$$

$$\text{or}\quad M=3n-2c_5-c_4=3\cdot 7-2\cdot 10-0=1. \tag{1}$$

where :

Sfi = the sum of the mobilities of the couplings,

k = spatiality of the mechanism,

n = number of cinematic elements,

c5 = sum of the couplings with mobility 1,

c4 = sum of the couplings with mobility 2.

3. Kinematic and statical analysis

Kinematic position of the finger is obtained with close vector chain method:

$$-(S_0+S_1)\bar{i}+l_2\bar{u}_2+l_3\bar{u}_3-a\bar{j}=0, \tag{2}$$

contains the versors:

$$\bar{u}_3=\bar{i}\sin\varphi_3+\bar{j}\cos\varphi_3, \tag{3}$$

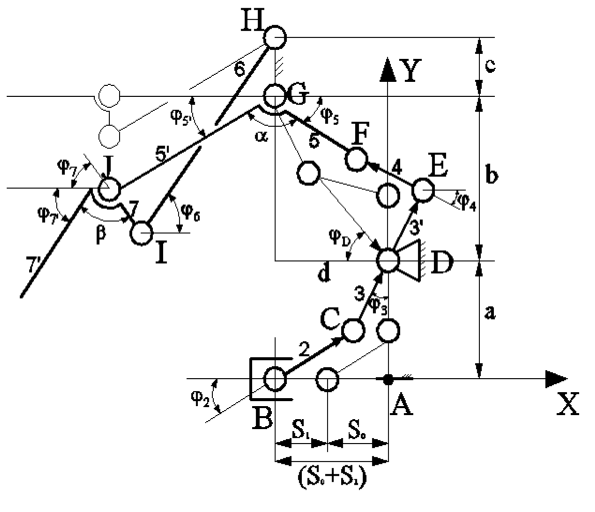


Figure 3: *The mechanism of a finger.*

thus squared,

$$(S_0+S_1)^2+l_3^{\,2}+a^2-l_2^{\,2}-$$
$$-2(S_0+S_1)l_3\sin\varphi_3-2l_3a\cos\varphi_3=0, \tag{4}$$

has the form:

$$A_I\sin\varphi_3+B_I\cos\varphi_3+C_I=0, \tag{5}$$

where:

$$A_I = -2(S_0 + S_1)l_3,$$
$$B_I = 2l_3 a,$$
$$C_I = (S_0 + S_1)^2 + l_3{}^2 + a^2 - l_2{}^2. \qquad (6)$$

The solution to the equation (5),

$$\varphi_3 = 2arctg\frac{A_I + \sqrt{A_I{}^2 + B_I{}^2 - C_I{}^2}}{B_I - C_I}, \qquad (7)$$

For S1=0; in contour DEFGD

$$l_3\bar{u}_3 + l_4\bar{u}_4 + l_5\bar{u}_5 + l_0\bar{u}_0 = 0, \qquad (8)$$

with:

$$l_0 = \sqrt{b^2 + d^2}, \bar{u}_5 = -\bar{i}\cos\varphi_5 + \bar{j}\sin\varphi_5, \bar{u}_0 =$$
$$= +\bar{i}\cos\varphi_0 - \bar{j}\sin\varphi_0, tg\varphi_0 = \frac{b}{d} \qquad (9)$$

we can write the equations:

$$l_{3'}{}^2 + l_5{}^2 + l_0{}^2 - l_4{}^2 +$$
$$+ 2l_{3'}l_5(-\sin\varphi_3\cos\varphi_5 + \cos\varphi_3\sin\varphi_5) + \qquad (10)$$
$$+ 2l_{3'}l_0(+\sin\varphi_3\cos\varphi_0 - \cos\varphi_3\sin\varphi_0) +$$
$$+ 2l_5 l_0(-\cos\varphi_5\cos\varphi_0 - \sin\varphi_5\sin\varphi_0) = 0,$$

in form:

$$A_{II}\sin\varphi_5 + B_{II}\cos\varphi_5 + C_{II} = 0, \qquad (11)$$

with:

$$A_{II} = 2l_5(l_{3'}\cos\varphi_3 - l_0\sin\varphi_0),$$
$$B_{II} = -2l_5(l_{3'}\sin\varphi_3 + l_0\cos\varphi_0),$$
$$C_{II} = l_{3'}{}^2 + l_5{}^2 + l_0{}^2 - l_4{}^2 - 2l_{3'}l_0\sin(\varphi_0 - \varphi_3), \qquad (12)$$

and,

$$\varphi_5 = 2arctg\frac{A_{II} - \sqrt{A_{II}{}^2 + B_{II}{}^2 - C_{II}{}^2}}{B_{II} - C_{II}}, \qquad (13)$$

In contour GJIHG:

$$l_{5'}\bar{u}_{5'} + l_7\bar{u}_7 + l_6\bar{u}_6 - c\bar{j} = 0, \qquad (14)$$

with the versors:

$$\bar{u}_{5'} = -\bar{i}\cos\varphi_{5'} - \bar{j}\sin\varphi_{5'},$$
$$\bar{u}_7 = \bar{i}\cos\varphi_7 - \bar{j}\sin\varphi_7, \qquad (15)$$
$$\varphi_{5'} = 180^0 - (\alpha + \varphi_5).$$

$$l_{5'}{}^2 + l_7{}^2 + c^2 - l_6{}^2 +$$
$$+ 2l_{5'}l_7(-\cos\varphi_{5'}\cos\varphi_7 + \sin\varphi_{5'}\sin\varphi_7) + \qquad (16)$$
$$+ 2l_{5'}c\sin\varphi_{5'} + 2l_7 c\sin\varphi_7 = 0,$$

$$A_{III}\sin\varphi_7 + B_{III}\cos\varphi_7 + C_{III} = 0, \qquad (17)$$

with:

$$A_{III} = 2l_7(l_{5'}\cos\varphi_{5'} + c),$$
$$B_{III} = -2l_7 l_{5'}\cos\varphi_{5'},$$
$$C_{III} = l_{5'}{}^2 + l_7{}^2 + c^2 - l_6{}^2 + 2l_{5'}c\sin\varphi_{5'}. \qquad (18)$$

where:

$$\varphi_7 = 2arctg\frac{A_{III} - \sqrt{A_{III}{}^2 + B_{III}{}^2 - C_{III}{}^2}}{B_{III} - C_{III}}, \qquad (19)$$

and,

$$\varphi_{7'} = 180^0 - (\beta + \varphi_7). \qquad (20)$$

In previous determination, the contour equations were resolved by eliminating the versor (that is the unknown angle) of the intermediate rods.

To determine the forces, we need to know these angles. Since the connecting rods are uncharged, therefore the forces will be along them.

According to the positioning towards the X-axis, the versors

$$\bar{u}_2 = \bar{i}\cos\varphi_2 + \bar{j}\sin\varphi_2,$$
$$\bar{u}_4 = -\bar{i}\cos\varphi_4 + \bar{j}\sin\varphi_4,$$
$$\bar{u}_6 = \bar{i}\cos\varphi_6 + \bar{j}\sin\varphi_6. \qquad (21)$$

By identification in the contour equations (2) and (10), by projection on the X-axis, we obtain, respectively:

$$-(S_0 + S_1) + l_2\cos\varphi_2 + l_3\sin\varphi_3 = 0,$$
$$l_{3'}\sin\varphi_{3'} - l_4\cos\varphi_4 - l_5\cos\varphi_5 + l_0\cos\varphi_0 = 0,$$
$$-l_{5'}\sin\varphi_{5;'} + l_7\cos\varphi_7 + l_6\cos\varphi_6 = 0. \qquad (22)$$

so that:

$$\cos\varphi_2 = \frac{1}{l_2}\left(S_0 + S_1 - l_3\sin\varphi_3\right), \tag{23}$$

$$\cos\varphi_4 = \frac{1}{l_4}\left(-l_5\cos\varphi_5 + l_0\cos\varphi_0 + l_{3'}\sin\varphi_{3'}\right), \tag{24}$$

$$\cos\varphi_6 = \frac{1}{l_6}\left(l_{5'}\cos\varphi_{5'} - l_7\cos\varphi_7\right). \tag{25}$$

The reactions in the system will be determined, this time, starting $\bar{F}_m$ from the motor force from the actuator, therefore the dyad type kinematic chains will reconfigure, the first element entering the first dyadic group. Thus, the statically determined dyads, for the calculation of the reactions, will be made up of the elements 1-2, 3-4, 5-7, the element 6 remaining alone (Figure 4) as a final element.

In group ABC, with $\bar{F}_m$ given, resultsfrom the projection on the X-axis (Figure 4, a):

$$F_C = \frac{F_m}{\cos\varphi_2}. \tag{26}$$

In group DEF, with $\bar{F}_C$ determined, from $\sum M_D = 0$, results (Figure 4,b), for the arms DC' and DE' of the forces.

In group GJI the difficulty of the unknown resistant force $\bar{F}_r$ appears, so that, along with the 2x3 unknowns, as reactions in the articulations G, J and I, a seventh unknown appears for the 2x3 equilibrium equations of the elements 2 and 3. But since $\bar{F}_r$ has a known direction, along bar G the unknowns are reduced to G, so system 5-7 statically determined.

From the sum of moments in J, for element 7 results the correlation (Figure 4,c.):

$$F_r l_{7'} = F_I l_7 \sin\left(\varphi_6 + \varphi_7\right). \tag{28}$$

Thus:

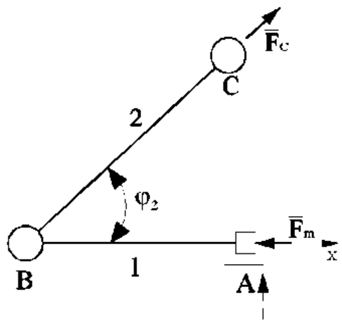
$$F_G^{\,X} + F_r\frac{l_{7'}\cos\varphi_6}{l_7\sin(\varphi_6+\varphi_7)} - F_r\sin\varphi_{7'} + F_F\cos\varphi_4 = 0,$$

$$F_G^{\,Y} + F_r\left(\frac{l_{7'}\sin\varphi_6}{l_7\sin(\varphi_6+\varphi_7)} + \cos\varphi_{7'}\right) - F_F\sin\varphi_4 = 0,$$

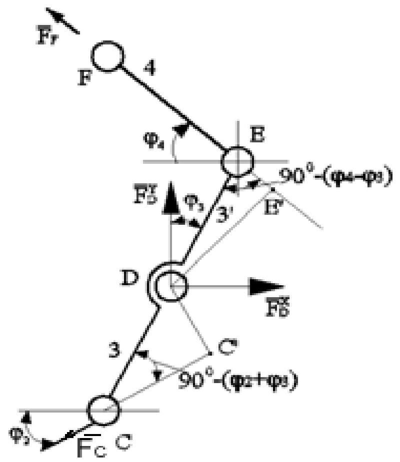
$$\sum M_J^{(5)}, F_G^{\,X} l_{5'}\sin\varphi_{5'} - F_G^{\,Y} l_{5'}\cos\varphi_{5'} +$$

$$+F_F\cos\varphi_4(l_{5'}\sin\varphi_{5'} - l_5\sin\varphi_{5'}) + F_F\sin\varphi_4(l_{5'}\cos\varphi_{5'} + l_5\cos\varphi_{5'}) = 0.$$

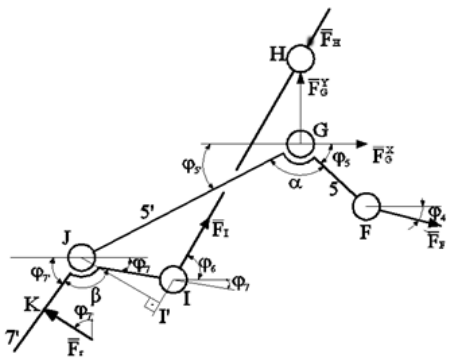
(29



a



b



c

Figure 4: *Statical schemes.*

$$F_c l_3\sin\left[90^0 - (\varphi_2+\varphi_3)\right] = F_F l_{3'}\sin\left[90^0 - (\varphi_4-\varphi_3)\right],$$

$$F_F = F_C\frac{l_3}{l_{3'}}\cdot\frac{\cos(\varphi_2+\varphi_3)}{\cos(\varphi_4-\varphi_3)}. \tag{27}$$

system containing the unknowns $F_G{}^X$, $F_G{}^Y$ and F_r:

$$\begin{aligned}
&F_G{}^X + F_r\left(\frac{l_{7'}\cos\varphi_6}{l_7\sin(\varphi_6+\varphi_7)} - \sin\varphi_{7'}\right) = -F_F\cos\varphi_4,\\
&F_G{}^Y + F_r\left(\frac{l_{7'}\sin\varphi_6}{l_7\sin(\varphi_6+\varphi_7)} + \cos\varphi_{7'}\right) = F_F\sin\varphi_4,\\
&F_G{}^X l_{5'}\sin\varphi_{5'} - F_G{}^Y l_{5'}\cos\varphi_{5'} = F_F\cos\varphi_4(l_5\sin\varphi_{5'} -\\
&- l_{5'}\sin\varphi_{5'}) - F_F\sin\varphi_4(l_{5'}\cos\varphi_{5'} + l_5\cos\varphi_{5'}).
\end{aligned} \tag{30}$$

More simple relations would result, if the kinematic groups form the resistant force would be operated, that is, in sequence by the group of elements 6-7, 4-5, 2-3.

4. CAD design and functional simulation

The stages of the 3D design, in according with the technological logic are partial present in Figure 5, what are[7]:

a. sketch of the piece what will be extrudated ;

b. defining the function *Extrude*(Figure 5,a);

c. obtaining the piece after two successive extrudates and opening the menu to define the chamfers(Figure 5,b);

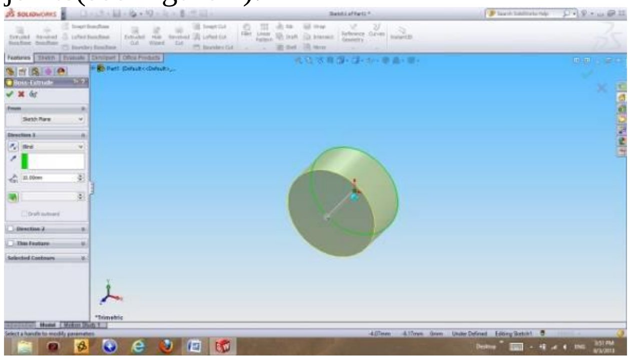
d. opening the menu –dialog box – for to define the direct connections;

e. opening the dialog box for to solid define *Cut-Extrude*(Figure 5,c);

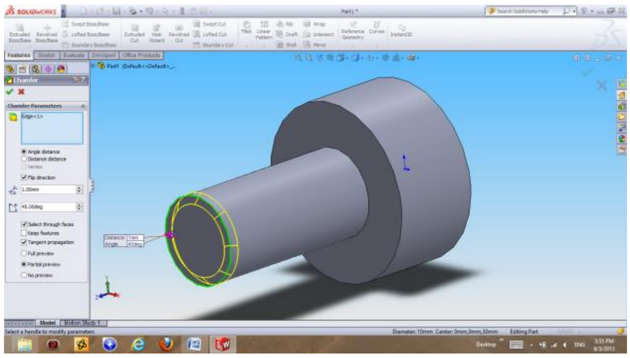
f. obtained the final version of the pieces after 3D modeling.

After modeling 3D for all pieces, the next stage is to assembly all components for to obtain the final assembly, and 3D model of the gripper(see Figure 6)[8].

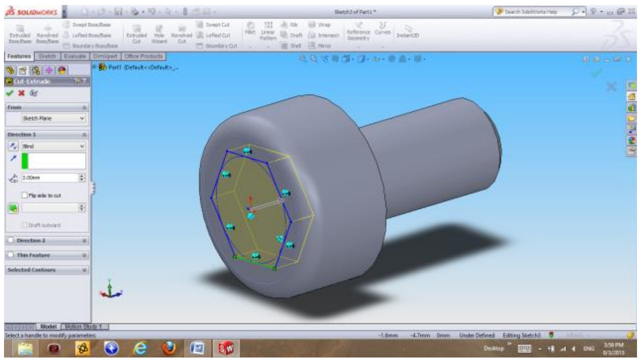
Since the two-fingered gripping mechanisms(see Figure 6) show low gripping possibilites, we attached jaw systems on the phalanxes of the fingers, using spherical joints(see Figure 7).



a



b



c

Figure 5: *Stages of the 3D design.*

These jaws can attach to the surface of the gripped object, regardless of its geometry. Each jaw contacts the object in 3 points(see Figure 7). This allows the gripper to grasp objects with no matter how complex geometries.

A functional simulation (Figure 8,a,b) was made to check the correct work and to identify the solutions to obtain the optimum variant for this gripper.

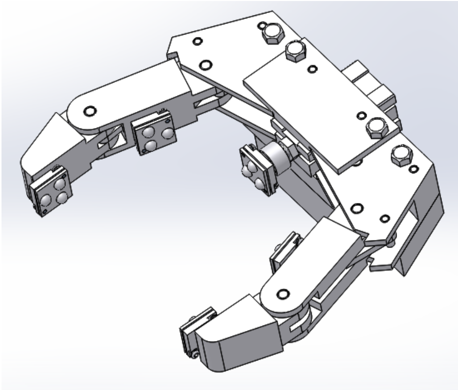


Figure 6: *The two fingered anthropomorphic gripper [8].*

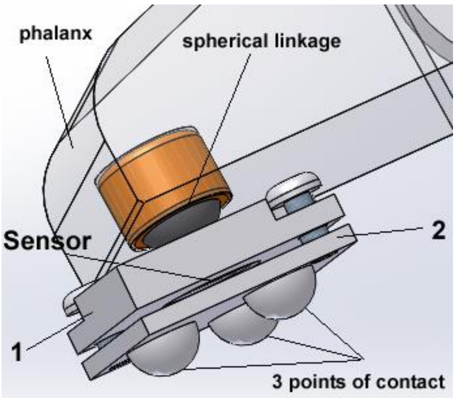
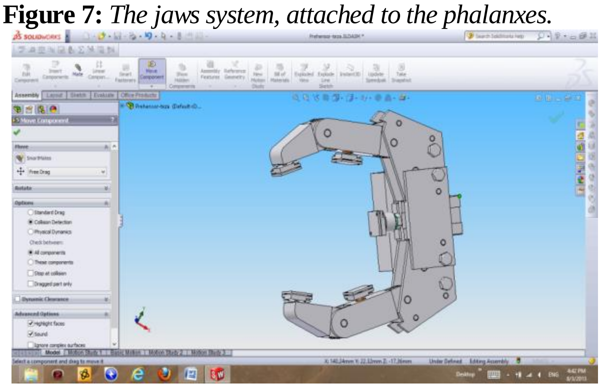
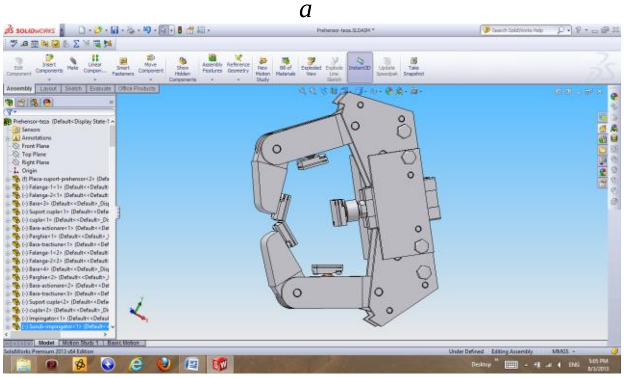


Figure 7: *The jaws system, attached to the phalanxes.*



a



b

Figure 8: *The functional simulation: open position (a); closed position(b).*

5. Conclusions

The next conclusion can be formulated in according to the considerations presented:

a) The main stages for to design the anthropomorphic mechanical grippers are: structural synthesis and analysis, kinematics synthesis and analysis, static synthesis and analysis, constructive design and 3D model and functional simulation.

b) This gripper can be obtained using two fingers with two phalanges per finger used anti-parallelogram mechanisms. This is a simple structure with low cost and with elevated fiability.

Acknowledgments

We express our gratitude to the company CLOOS from Germany and its representative in Romania, Timisoara ROBCON company, to support research whose results are presented in part in this paper.

References

[1] Staretu, I., *Gripping systems*, Derc Publishing House, Tewksbury, Massachusetts,USA, 2011.

[2] Information on http:// www.barrett.com/ robot/ products-hand.htm.

[3] Butterfass, J. et al., Design and Experience with DLR Hand II, *Proceedings of the World Automation Congress 2004*, Seville, Spain, 2004.

[4] Kochan, A., Shadow delivers first hand, *Industrial Robot Journal*, V. 32, Issue 1, pp.15/16, 2005.

[5] Bolboe, M., Structura mecanica, acţionarea, comanda si controlul prehensoarelor cu degete. Studiu de caz, *Mechanisms and Manipulators Journal*(in Romanian), Vol 10, Nr.2, ARoTMM-IFToMM, Bucharest, 2011, pp.15-18.

[6] Bolboe, M., Stareţu, I., Mechanischer Entwurf, Antrieb, Steuerung und Kontrolle Antropomorpher Greifmechanismen Fallstudien, *Mechanisms and Manipulators Journal*(in Romanian), Vol. 6, nr.2, ARoTMM-IFToMM, Bucharest, 2007, pp.27-32.

[7] Information on http://mecha.skku.ac.kr/board/.

[8] Bolboe, M., *Theoretical and experimental researches regarding the anthropomophic gripping systems with a reduced number of fingers, designed for robots*, PhD thesis(in Romanian), Transilvania University of Brasov, 2013.