ANTHROPOMORPHIC MODULAR RECONFIGURABLE GRIPPER WITH THREE FINGERS-DESIGN AND PROTOTYPE

Ionel STARETU
Transilvania University of Brasov, Brasov, email :istaretu@yahoo.com

In this paper one anthropomorphic modular reconfigurable gripper for robots are described, including a prototype. For the first time the stages of synthesis, analysis design and functional simulation are presented. The structural synthesis of the anthropomorphic grippers for robots can be made regarding the following main criteria: the number of fingers, the number of phalanxes, the relative dimensions of the phalanxes, the relative position of the fingers, the degree of freedom of the gripping mechanism and the characteristic constructive elements used. We choose a version with three identical fingers with three phalanxes on finger. The kinematic synthesis is used to obtain a correct closing of the finger and of the gripping mechanism. The function of position, the function of speeds and the function of acceleration for characteristic points are obtained from the kinematic analysis. The static synthesis solves the problem to obtaining the necessary gripping force on each finger and the total gripping force. The calculation of strength was made in function of the internal forces which act between elements. With the constructive dimensions a 3D model can be obtained using CATIA soft. Some aspects regarding functional CAD and virtual simulations are shown too. For one variant of this type of gripper, with three fingers, the technical documentation is completed and the technical project has all the conditions for practical achievement and a prototype was made. There are two main constructive modules: the support – the palm and the finger. Main technical characteristics of the prototype are indicated.

Keywords: grasp, anthropomorphic gripper, modular structure, reconfigurable, prototype.

1. INTRODUCTION

The anthropomorphic grippers are of increased interest due to raising applicability to industrial robots but also to other types of robots, especially humanoids service robots.

Currently there is a relatively large variety of such grippers [1], [2], [3], [4], [5], [6], [7] [8], which have a high price, even in some cases very high, which discourages attempts to introduce them in current applications.

The paper first briefly refers to the class of modular reconfigurable anthropomorphic grippers proposed by the author.

In terms of modularization, this class is based on a generic version, which may have a variable number of fingers. This number ranges from 2 to 6, but there is as well the opportunity to make a gripper in a wide range of sizes, from small sizes (0.75, 0.5, 0.25, etc. reported to the human hand) to larger versions (1.5, 2, 2.5, etc. reported to the human hand). Thus, a wide range of weights (from several grams to several kilograms, or even tens of kilograms) can be manipulated.

The possibility of being reconfigurable refers to the use of a platform where fingers (three or more) can have more relative positions only through disassembling and assembling elsewhere, without removing the platform off the robot arm. Thus, such a gripper, at a lower price, can replace several separate grippers or may cover a significant percentage, even up to 60% of the usefulness of a continuously reconfigurable gripper, and in this case economic efficiency is ensured (generally at a price of 20% or even lower, utility can be up to 50% or even 70%).

In this paper for a variant of this class of anthropomorphic grippers, that is a gripper with three fingers, the main theoretical and construction features are illustrated and a prototype is described as well.
Obviously, all considerations can be extrapolated to variants with fewer fingers, respectively, two or more fingers, four, five or even six.

2. STRUCTURAL AND KINETOSTATIC SYNTHESIS

2.1. Structural Synthesis

The structural synthesis seeks to set possible configurations and the structure of a finger so that it has the largest degree of utility possible.

Looking at possible configurations four are considered significant (see Figure 1), which can be obtained by proper installation of the three fingers on the same platform.

![Figure 1. Significant configuration of three fingers](image)

In connection with the structure of a finger it may have two or three phalanxes (see Figure 2), possibilities of which we opted for three phalanxes, for a greater degree of utility (see Figure 2b).

![Figure 2. Fingers with two phalanxes (a) and three phalanxes (b)](image)

There is the possibility of using four phalanxes too, or even five, which must be duly justified, however, as there are clearly higher prices.

2.2. Kinetostatic Synthesis

In this phase we determine linear and angular dimensions of components so that the fingers close properly (kinematic synthesis purpose), and the given weight can be gripped and handled (static synthesis purpose).

3. ANALYSIS

3.1. Structural analysis

The mechanism of the finger (see Figure 3) is a poly-contour mechanism with two outside connection \( L=2 \) (\( v_1, F_1; v_{P1}, F_{P1} \) – see Figure 4,a) and degree of freedom \( M=1 \).

The degree of freedom is obtained with \( M = \sum M_i - \sum f_c \), where \( M_i \) is the degree of freedom for mono-contour i mechanism and \( \sum f_c \) is the degree of freedom for common joints (see Figure 4,b).

For each mono-contour mechanism the degree of freedom is obtained with \( M = \sum f_i - \chi_k \) (where \( \sum f_i \) is the degree of freedom of the joints and \( \chi_k \) is cinematic degree of the mono-contour k mechanism [9]).
For the mechanism shown in Figure 3, in accordance with the graph of Figure 4, the following relations are obtained:

\[ M_1 = f_A + f_B + f_C + f_D - \chi = 1 + 1 + 1 + 1 - 3 = 1 \]
\[ M_{II} = f_B + f_C + f_D + f_E - \chi = 1 + 1 + 1 + 1 - 3 = 1 \]  
\[ M_{III} = f_C + f_D + f_E + f_F - \chi = 1 + 1 + 1 + 1 - 3 = 1 \]

\[ \sum f_C = f_D + f_E = 1 + 1 = 2. \]

The degree of freedom will be:

\[ M = M_1 + M_{II} + M_{III} - \sum f_C = 1 + 1 + 1 - 2 = 1 \]

\[ M = 1 \] has the following significance: one independent movement (speed): \( v_1 = s_1 \) and one function of the external forces: \( F_1 = F_1(F_{p1}) \). \( L - M = 1 \) represents one function of movement: \( v_{p1} = v_{p1}(v_1) \) and one independent force: \( F_{p1} \) – the contact force between finger and grasped object.

3.2. Kinematic analysis

The function of position, the function of speed and the function of acceleration for characteristic points are obtained from the cinematic analysis. The vectorial close chain method is used successively for each mono-contour mechanism. The vectorial equations are:

\[ A C + C D + D D' + D' A = 0 \]
\[ D E + E F + F G + G D = 0 \]
\[ E N + N M + M L + L E = 0 \]

The implicit form for the equation of position is: \( \varphi_{72i} = \varphi_{72i}(s_1) \), \( i \) the number of the fingers: \( i = 1, 2, 3 \).

The functions for speeds are the derivative function of time of the functions for positions and the functions for accelerations are the derivative of the functions for speeds:

\[ \dot{v}_{p1} = \varphi_{72i}, \quad \ddot{v}_{p1} = \varphi_{72i} \]
3.3. Static analysis

The function of the external forces is obtained from the theorem of balance between the powers of entrance and emergence of mechanism, \( v_i \cdot F_i + v_Pi \cdot F_Pi = 0 \), and

\[
F_i = -\frac{v_Pi \cdot F_Pi}{v_i}
\]  

(4)

The internal forces are calculated using the theorem of the joints and, afterwards, with the balance static equations of the mobile elements [10],[11].

4. CONSTRUCTIVE DESIGN AND 3D MODEL

The calculation of strength was made in function of the internal forces which act between elements.

With the constructive dimensions a 3D model can be obtained using CATIA soft. There are two main constructive modules: the support – the palm (see Figure 6a) and the finger (see Figure 6b)[11],[12],[13],[14],[15].

With these modules two three-finger versions can be obtained (see Figure 1), the fingers having possible parallel (see Figure 7a) or concurrent movements (see Figure 7b).

A functional simulation (see Figure 8) was made to check the correct work and to identify the solutions to obtain the optimum variant for this gripper.
This gripper, with one specific intermediary piece, can be mounted on any industrial commercial robot (see CAD simulation in Figure 9). One of its configurations can be obtained, during the gripper is mounted on robot, with change the relative position of the fingers only, regarding the form of the grasped object.

For functional simulation of the grasped operations, the robot with the gripper were transferred in virtual reality – VRML soft (see Figure 10). Here we can test different grasping operations for different objects. Then, the results, for one correct grasp, can be used for programming the real gripper.

5. PROTOTYPE-PERFORMANCE AND TEST

On the basis of the technical documentation prepared in accordance with technical rules in force a prototype of the gripper analyzed in this paper was issued (see Figure 11a). In Figure 11b, as a first experimental form and functional testing, gripping a spherical body with this prototype is exemplified. The main technical characteristics of this prototype are: degree of freedom: M=3; weight hand: 12 N; payload: 40 N; gripping force: \( \sim 30 \text{ N/finger} \); dimensions: finger : 1:1 human fingers size and hand: 140x140x100 mm.
For the drive, pneumatic linear motors are used. The prototype can be equipped with contact sensors (for example, type CZN-CP15), and command and control can be ensured through appropriate equipment. After providing corresponding equipment, the prototype will be mounted on a robot and will be fully tested in various gripping operations, including handling. In the first stage testing will be done in CAD environment (including gripping phase), test done in a preliminary stage without the object to grip (Fig. 9), then functional simulation will be possible in virtual environment (e.g. VRML) in order to establish data for accurate virtual gripping and their transmission to the real gripper – the prototype [16], [17].

6. CONCLUSION

In according to the considerations presented the next conclusion can be formulated:

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

b. The family of the mechanical anthropomorphic modular reconfigurable grippers for robots with two, three, four and five identically fingers has more variants, what can be obtained in accordance with the number and the relative position of the fingers.

c. The grippers with three fingers can be obtained using two main modules: the support – the palm and the finger. With these two modules can be obtained any variants with three and two fingers too.

d. Discontinuous modular reconfigurable anthropomorphic grippers have certain advantages, especially on the cost, but also functional, compared to other anthropomorphic grippers, including those with continuous reconfiguration possibility.

7. REFERENCES