Design, Prototype and Command for an Anthropomorphic Modular Reconfigurable Gripper with Three Fingers for Industrial Robots

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Abstract: This paper describes one anthropomorphic modular reconfigurable gripper for robots, including a prototype and one command solution. 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 have chosen 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 static synthesis solves the problem to obtaining the necessary gripping force on each finger and the total gripping force. With the constructive dimensions a 3D model can be obtained using CATIA soft. Aspects regarding functional CAD and virtual simulations are shown too. For one variant of this type of gripper, 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. Some aspects regarding actuated and command schemes are shown.

Key words: Grasp, anthropomorphic gripper, modular structure, reconfigurable, simulation, prototype, command.

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 [1-7], 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 authors. 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 (two, 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

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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 (Fig. 1), which can be obtained by proper installation of the three fingers on the same platform.

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

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

Fig. 1 Significant configuration of the three fingers.

Fig. 2 Fingers with 2 phalanxes and with 3 phalanxes.

weight can be gripped and handled (static synthesis purpose).

3. Analysis

3.1 Structural Analysis

The mechanism of the finger (see Fig. 3) is a poly-contour mechanism with two outside connection $L = 2$ ($v_1, F_1; v_{P1}, F_{P1}$, Fig. 4a) and degree of freedom $M = 1$. The degree of freedom is obtained with $M = \sum M_k - \sum f_c$, where M_k is the degree of freedom for mono-contour $k = I, II, III$ mechanism and $\sum f_c$ is the degree of freedom for common joints (Fig. 4b). 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 χ_k is cinematic degree of the mono-contour k mechanism [8]).

For the mechanism shown in Fig. 3, in accordingly with the graph of Fig. 4b and the formula $M = \sum f_i - \chi_k$, the following relations are obtained:

$$M_I = f_A + f_B + f_C + f_D - \chi_I = 1 + 1 + 1 + 1 - 3 = 1$$

$$M_{II} = f_D + f_E + f_F + f_G - \chi_{II} = 1 + 1 + 1 + 1 - 3 = 1 \quad (1)$$

$$M_{III} = f_L + f_M + f_N + f_E - \chi_{III} = 1 + 1 + 1 + 1 - 3 = 1$$

and $\sum f_c = f_D + f_E = 1 + 1 = 2$. The degree of freedom will be:

$$M = M_I + M_{II} + M_{III} - \sum f_c = 1 + 1 + 1 - 2 = 1 \quad (2)$$

Fig. 3 The structural scheme of the finger.

Fig. 4 The block scheme and the graph of the mechanism.

$M = 1$ 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: $v_{P1} = v_{P1}(v_1)$ or $\varphi_{72-P1} = \varphi_{72-P1}(s_1)$ and one independent force: F_{P1} is 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 P_i points ($i = 1, 2, 3$) are obtained from the cinematic analysis. The cinematic analysis is performed using the method of the closed vectorial contour [8, 9], applied successively to the vector contours corresponding to the mono-contour mechanisms. For the contour $ACDD'$ (Fig. 5), the vector equation is $\overrightarrow{AC} + \overrightarrow{CD} + \overrightarrow{DD'} + \overrightarrow{D'A} = \vec{0}$, and in matrix like form, the scalars of the vectors are:

$$\begin{aligned} AC &= l_1 \begin{bmatrix} \cos \varphi_{10} \\ \sin \varphi_{10} \\ 0 \end{bmatrix}, CD = l_{31} \begin{bmatrix} \cos \varphi_{31} \\ \sin \varphi_{31} \\ 0 \end{bmatrix}, \\ DD' &= d_2 \begin{bmatrix} \cos \pi/2 \\ \sin \pi/2 \\ 0 \end{bmatrix}, D'A = d_1 \begin{bmatrix} \cos \pi \\ \sin \pi \\ 0 \end{bmatrix}. \end{aligned} \quad (3)$$

In addition, the corresponding scalar system is:

$$\begin{cases} l_1 \cos \varphi_{10} + l_{31} \cos \varphi_{31} + d_2 \cos \pi/2 + d_1 \cos \pi = 0 \\ l_1 \sin \varphi_{10} + l_{31} \sin \varphi_{31} + d_2 \sin \pi/2 + d_1 \sin \pi = 0 \end{cases} \quad (4)$$

This system leads to the position function:

$$\varphi_{31} = \varphi_{31}(s_1)$$

According to Fig. 6 the equation corresponding to the closing of the vector contour in the case of DEFG mechanism is:

$$\overrightarrow{DE} + \overrightarrow{EF} + \overrightarrow{FG} + \overrightarrow{GD} = \vec{0} \quad (5)$$

that leads to the function that transfers the positions $\varphi_{41} = \varphi_{41}(\varphi_{31}, s_1)$.

In matrix like form the scalars of the vectors are:

$$\begin{aligned} DE &= l_{32} \begin{bmatrix} \cos \varphi_{32} \\ \sin \varphi_{32} \\ 0 \end{bmatrix}, EF = l_{41} \begin{bmatrix} \cos \varphi_{41} \\ \sin \varphi_{41} \\ 0 \end{bmatrix} \\ FG &= l_5 \begin{bmatrix} \cos \varphi_5 \\ \sin \varphi_5 \\ 0 \end{bmatrix}, GD = l_0 \begin{bmatrix} \cos \varphi_0 \\ \sin \varphi_0 \\ 0 \end{bmatrix}. \end{aligned} \quad (6)$$

Moreover, the corresponding scalar system is:

$$\begin{cases} l_{32} \cos \varphi_{32} + l_{41} \cos \varphi_{41} + l_5 \cos \varphi_5 + l_0 \cos \varphi_0 = 0 \\ l_{32} \sin \varphi_{32} + l_{41} \sin \varphi_{41} + l_5 \sin \varphi_5 + l_0 \sin \varphi_0 = 0 \end{cases} \quad (7)$$

Taking into consideration that φ_{32} is a function of φ_{31} and s_1 , φ_{41} can be determined.

According to Fig. 7, the equation associated to the closing of the vector contour of the mechanism ENML is:

$$\overrightarrow{EN} + \overrightarrow{NM} + \overrightarrow{ML} + \overrightarrow{LE} = \vec{0} \quad (8)$$

In matrix like form the scalars of the vectors are:

Fig. 5 Closed ACDD' vectorial contour.

Fig. 6 Closed DEFG vectorial contour.

Fig. 7 Closed ENML vectorial contour.

$$EN = l_{42} \begin{bmatrix} \cos \varphi_{42} \\ \sin \varphi_{42} \\ 0 \end{bmatrix}, NM = l_{71} \begin{bmatrix} \cos \varphi_{71} \\ \sin \varphi_{71} \\ 0 \end{bmatrix} \quad (9)$$

$$ML = l_6 \begin{bmatrix} \cos \varphi_6 \\ \sin \varphi_6 \\ 0 \end{bmatrix}, LE = l_{33} \begin{bmatrix} \cos \varphi_{33} \\ \sin \varphi_{33} \\ 0 \end{bmatrix}$$

In addition, the corresponding scalar system is:

$$\begin{cases} l_{42} \cos \varphi_{42} + l_{71} \cos \varphi_{71} + l_6 \cos \varphi_6 + l_{33} \cos \varphi_{33} = 0 \\ l_{42} \sin \varphi_{42} + l_{71} \sin \varphi_{71} + l_6 \sin \varphi_6 + l_{33} \sin \varphi_{33} = 0 \end{cases} \quad (10)$$

The solution of the system (10), leads to the function associated to the positions transfer for the element 7, is:

$$\varphi_{71} = \varphi_{71}(s_1) \text{ and then } \varphi_{72} = \varphi_{72}(s_1).$$

So, the implicit form for the equation of position is: $\varphi_{72i} = \varphi_{72i}(s_1)$, i is 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:

$$\dot{v}_{Pi} = \dot{\varphi}_{72i}, \quad \dot{a}_{Pi} = \dot{v}_{Pi} \quad (11)$$

3.2 Static Analysis

The function of the external forces is obtained from the theorem of balance between the powers of entrance and emergence of mechanism, $v_i \cdot F_i + v_{Pi} \cdot F_{Pi} = 0$, if the friction is null, and

$$F_i = - \frac{v_{Pi} \cdot F_{Pi}}{v_i} \quad (12)$$

(a)

The internal forces are calculated using the theorem of the joints and, afterwards, with the balance static equations of the mobile elements [8-10].

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 (Fig. 8a) and the finger (Fig. 8b) [11-14].

With these modules four three-finger versions can be obtained (Fig. 1). In Fig. 9 are shown two versions: the fingers having parallel movement (Fig. 9a) and concurrent movement (Fig. 9b).

A functional simulation (Fig. 10) 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 (CAD simulation in Fig. 11). 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 (Fig. 12). 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.

(b)

Fig. 8 The main constructive modules.

Fig. 9 Modular reconfigurable grippers with three fingers: (a) parallel movement and (b) concurrent movement.

Fig. 10 The CAD functional simulation.

Fig. 11 CAD example with the gripper mounted on robot.

5. Prototype-Performances 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 (Fig. 13a). In Fig. 13b, 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: ~ 30 N/finger; dimensions: finger: 1:1 human

fingers size and hand: $140 \times 140 \times 100$ mm.

6. Drive and Command Solution

For the drive, pneumatic linear motors are used. One actuated scheme for three fingers is shown in Fig. 14. The prototype can be equipped with contact sensors (for example, type CZN-CP15), and command and control can be ensured through appropriate equipment. A scheme of a particularized command for a finger of an reconfigurable gripper is shown in Fig. 15, for which are given some specific data of the used components, for a better orientation for those interested in carrying out projects. Using a pneumatic activator system, as if this scheme, requires the use of modular distributors of CPE14-M1BH-5/3B-QS-6 type, and the command and distribution system contains the sub-assemblies: drosale (LRMA-1/8-QS-8), adapter (SGS-M10x1.5), end plate (CPE14-PRS-EP), block expansion (CPE14-PRSEO-2), end element (CPE14-PRSGO-2), locking plate (CPE14-PRSB).

Fig. 12 The robot with gripper in VRML soft.

Fig. 13 Modular anthropomorphic reconfigurable three-fingered gripper prototype.

Fig. 14 Actuated pneumatic scheme.

Fig. 15 The command scheme.

In the operation process, the command of the gripping system is made following these steps:

- Issue start signal to close gripper (it can be vocal, electrical, electro-mechanical);
- Referral or not the prehensile object by the sensors mounted on the gripper fingers (operated independently);
- The introduction in the programmable module of a timing function with a role to prevent complete closure of the gripper without contacting the object: $F_i = 0$ - (ex.: IF $t \geq 3$ seconds and $F_i = 0$ THEN STOP);
- Contacting the object by at least one sensor on each finger;
- Gathering the object until it reaches gripping force set to one of the two sensors on each finger;
- Turn off engine's piston by the pneumatic distributor when the gripping force is reached, and termination gathering process;
- The gripper opening is made with a timing function, vocal, electrical or electromechanical, just as at start.

This control scheme can be used as a control mode for each finger, in case of anthropomorphic gripper with two, three, four, five or six fingers.

In conjunction with the command subsystem is the control subsystem, composed, in this case, by the contact-pressure sensors CZN-CP15 type, with the

following characteristics: used temperature: -40 °Cp to +85 °C, pressing force: 0.2 up to 100 N, intensity: 1 mA, lifetime for 35 N: 10 million operations and a signal convector IM36-22Ex-U type.

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. 11), 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 [15, 16].

5. Conclusions

In according to the considerations presented in this paper the next conclusions can be formulated:

(a) For to design the anthropomorphic mechanical grippers the main stages are: structural synthesis and analysis, kinematic synthesis and analysis, static synthesis and analysis, constructive design and 3D model and functional CAD 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 with one base, one palm and one sort of finger only;

(c) The four main versions of the reconfigurable anthropomorphic gripper with three fingers: with the fingers in linear position, with the fingers in isosceles position, with the fingers with parallel movement and with the fingers with concurrent movement, can be obtained using two main modules: the support: the palm and three identical fingers (only one sort of finger);

(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.

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