CLASS OF ANTHROPOMORPHIC MODULAR RECONFIGURABLE GRIPPERS WITH THREE OR FOUR FINGERS FOR ROBOT-DESIGN AND PROTOTYPE

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Abstract. In this paper, one class of anthropomorphic modular reconfigurable grippers for robots is described, including a prototype. First, the stages of synthesis, analysis design, and functional simulation are illustrated. The structural synthesis of the anthropomorphic grippers for robots is possible according to 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 that are used. We choose two versions: with three and four identical fingers with three phalanxes on finger. Kinematic synthesis is used to obtain correct closing of the finger and of the gripping mechanism. The function of position, the function of speed, and the function of acceleration for characteristic points are obtained from the kinematic analysis. The static synthesis solves the problem of obtaining the necessary gripping force on each finger, and the total gripping force. Strength calculation was possible based on the internal forces, which act between elements. By means of constructive dimensions, a 3D model can be obtained using CATIA software. Some aspects regarding functional CAD and virtual simulations are depicted as well. For one variant of this type of gripper, with three fingers, the technical documentation is completed and the technical project meets all the conditions for practical achievement, and a prototype was made. There are two main constructive modules: the support – the palm and the finger. The main technical characteristics of the prototype are indicated. Some aspects regarding actuated and command schemes are illustrated.

Key words: robots, anthropomorphic grippers, mechanism, modular design, reconfigurable gripper, functional simulation, prototype.

1. INTRODUCTION

Anthropomorphic grippers are of increased interest due to raising applicability of industrial robots, and of other types of robots, especially humanoid service robots.

Currently there is a relatively large variety of such grippers [1-8], whose price is high, in some cases very high, discouraging attempts of introducing them in current applications.

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

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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.

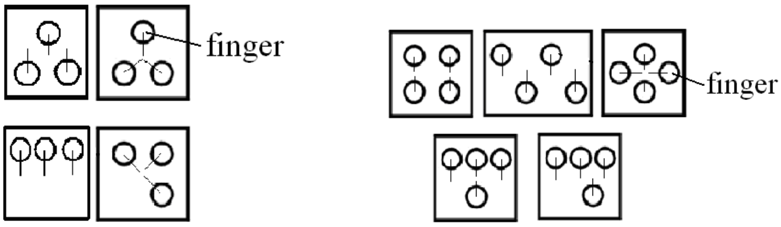
The possibility of being reconfigurable refers to the use of a platform where fingers (two, three or more) can have more relative positions only through disassembling and assembling elsewhere, without removing the platform off the robot arm. Thus, such a gripper, at a lower price, can replace several separate grippers or may cover a significant percentage, even up to 60%-70% 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. Some aspects regarding actuated and command schemes are shown too. 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 the possible configurations, four are considered significant (Fig. 1a), which can be obtained by proper installation of the three fingers on the same platform, and five configurations can be obtained with four fingers with the same fingers and another platform (Fig. 1b).



a b

Fig. 1 – Significant configuration of three fingers.

In connection with its structure, a finger may have two or three phalanxes (see Fig. 2). Among these possibilities, we opted for three phalanxes, for a greater degree of utility (see Fig. 2b).

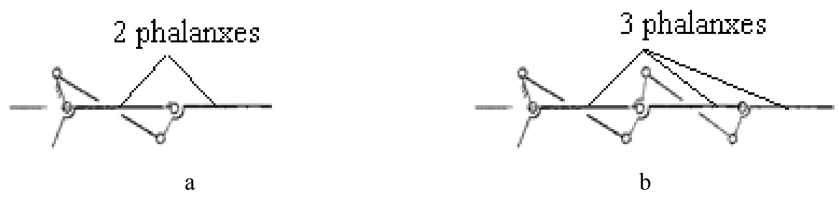


Fig. 2 – Fingers with two phalanxes (a) and three phalanxes (b).

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). This situation is obtained with a good correlation between the dimensions of the phalanxes and a good relative position of the fingers. The first and one intermediary position of the finger are shown in Fig. 3.

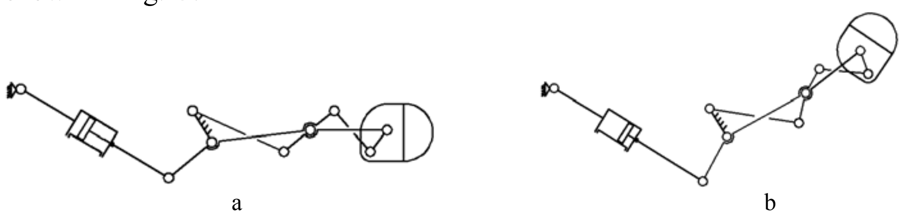


Fig. 3 – Two configurations of the finger.

3. ANALYSIS

3.1. STRUCTURAL ANALYSIS

The mechanism of the finger (see Fig. 4) is a poly-contour mechanism with two outside connections $L=2$ (v_1, F_1; v_{P1}, F_{P1} – see Fig. 5a) 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 Fig. 5b).

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 the kinematic degree of the mono-contour *k* mechanism [9]).

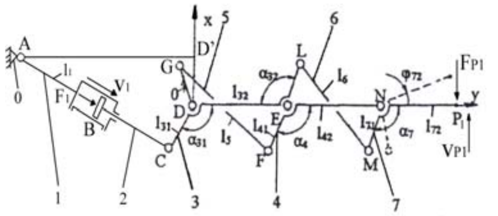


Fig. 4 – The structural scheme of the finger.

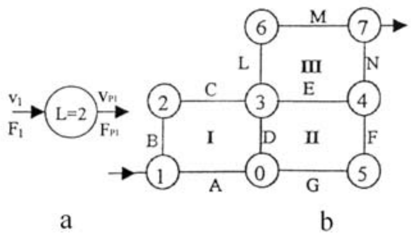


Fig. 5 – The block scheme and the graph of the mechanism.

For the mechanism shown in Figure 4, in accordance to the graph in Figure 5b, the following relations are obtained:

$$\begin{aligned} M_{\mathrm{I}} &= f_{\mathrm{A}} + f_{\mathrm{B}} + f_{\mathrm{C}} + f_{\mathrm{D}} - \chi_{\mathrm{I}} = 1+1+1+1-3=1 \\ M_{\mathrm{II}} &= f_{\mathrm{D}} + f_{\mathrm{E}} + f_{\mathrm{F}} + f_{\mathrm{G}} - \chi_{\mathrm{II}} = 1+1+1+1-3=1 \\ M_{\mathrm{III}} &= f_{\mathrm{L}} + f_{\mathrm{M}} + f_{\mathrm{N}} + f_{\mathrm{E}} - \chi_{\mathrm{III}} = 1+1+1+1-3=1, \end{aligned} \tag{1}$$

and $\Sigma f_{\mathrm{C}} = f_{\mathrm{D}} + f_{\mathrm{E}} = 1+1=2$.

The degree of freedom will be:

$$M = M_{\mathrm{I}} + M_{\mathrm{II}} + M_{\mathrm{III}} - \Sigma f_{\mathrm{C}} = 1+1+1-2=1. \tag{2}$$

$M=1$ has the following significance: one independent movement (speed) $v_1 = \mathrm{d}s_1/\mathrm{d}t$ and one function of the external forces: $F_1 = F_1(F_{\mathrm{P1}})$. $L-M = 1$ represents one function of movement: $v_{\mathrm{P1}} = v_{\mathrm{P1}}(v_1)$ 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 P_i points are obtained from the kinematic analysis. The kinematic analysis is performed using the method of the closed vectorial contour [9, 10], applied successively to the vector contours corresponding to the mono-contour mechanisms underlined in Fig. 4. For the contour ACDD' (Fig. 6), the vector equation is $\overrightarrow{\mathrm{AC}} + \overrightarrow{\mathrm{CD}} + \overrightarrow{\mathrm{DD'}} + \overrightarrow{\mathrm{D'A}} = \vec{0}$, and in matrix like form, the scalars of the vectors are:

$$\mathrm{AC}=s_1\begin{bmatrix}\cos\varphi_{10}\\ \sin\varphi_{10}\\ 0\end{bmatrix},\quad \mathrm{CD}=l_{31}\begin{bmatrix}\cos\varphi_{31}\\ \sin\varphi_{31}\\ 0\end{bmatrix},$$

$$\mathrm{DD}'=d_2\begin{bmatrix}\cos\frac{\pi}{2}\\ \sin\frac{\pi}{2}\\ 0\end{bmatrix},\quad \mathrm{D}'\mathrm{A}=d_1\begin{bmatrix}\cos\pi\\ \sin\pi\\ 0\end{bmatrix}. \tag{3}$$

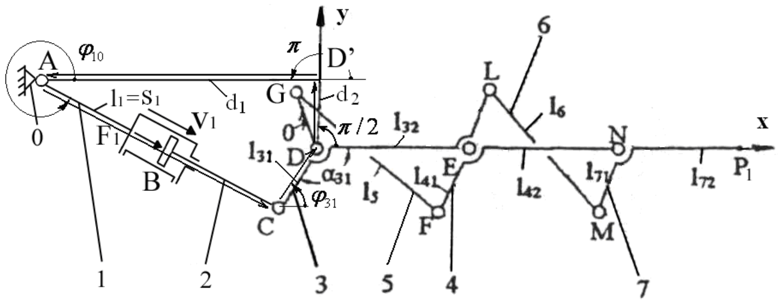


Fig. 6 – Closed ACDD' vectorial contour.

In addition, the corresponding scalar system is:

$$\begin{cases} s_1\cos\varphi_{10}+l_{31}\cos\varphi_{31}+d_2\cos\frac{\pi}{2}+d_1\cos\pi=0\\ s_1\sin\varphi_{10}+l_{31}\sin\varphi_{31}+d_2\sin\frac{\pi}{2}+d_1\sin\pi=0\end{cases}. \tag{4}$$

This system leads to the position function $\varphi_{31}=\varphi_{31}(s_1)$.

According to Fig. 7 the equation corresponding to the closing of the vector contour in the case of DEFG mechanism is:

$$\overrightarrow{\mathrm{DE}}+\overrightarrow{\mathrm{EF}}+\overrightarrow{\mathrm{FG}}+\overrightarrow{\mathrm{GD}}=\vec{0}, \tag{5}$$

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:

$$\mathrm{DE}=l_{32}\begin{bmatrix}\cos\varphi_{32}\\ \sin\varphi_{32}\\ 0\end{bmatrix},\ \mathrm{EF}=l_{41}\begin{bmatrix}\cos\varphi_{41}\\ \sin\varphi_{41}\\ 0\end{bmatrix},\ \mathrm{FG}=l_5\begin{bmatrix}\cos\varphi_5\\ \sin\varphi_5\\ 0\end{bmatrix},\ \mathrm{GD}=l_0\begin{bmatrix}\cos\varphi_0\\ \sin\varphi_0\\ 0\end{bmatrix}. \tag{6}$$

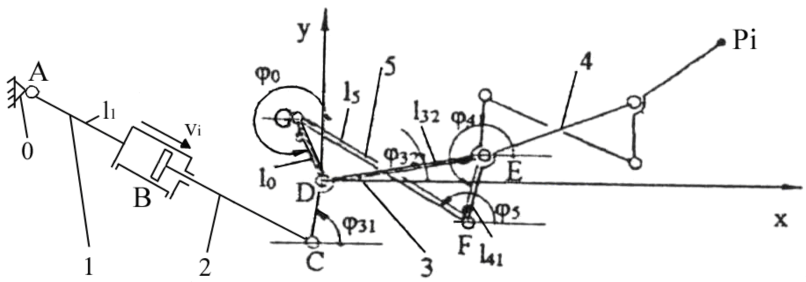


Fig. 7 – Closed DEFG vectorial contour.

Moreover, the corresponding scalar system is:

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

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

According to Fig. 8, the equation associated to the closing of the vector contour of the mechanism ENML is:

$$\overrightarrow{\mathrm{EN}} + \overrightarrow{\mathrm{NM}} + \overrightarrow{\mathrm{ML}} + \overrightarrow{\mathrm{LE}} = \vec{0}. \tag{8}$$

In matrix like form the scalars of the vectors are:

$$\begin{gathered} \mathrm{EN} = l_{42}\begin{bmatrix}\cos\varphi_{42}\\ \sin\varphi_{42}\\ 0\end{bmatrix}, \quad \mathrm{NM} = l_{71}\begin{bmatrix}\cos\varphi_{71}\\ \sin\varphi_{71}\\ 0\end{bmatrix}, \\ \mathrm{ML} = l_6\begin{bmatrix}\cos\varphi_6\\ \sin\varphi_6\\ 0\end{bmatrix}, \quad \mathrm{LE} = l_{33}\begin{bmatrix}\cos\varphi_{33}\\ \sin\varphi_{33}\\ 0\end{bmatrix}. \end{gathered} \tag{9}$$

In addition, the corresponding scalar system is:

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

The solution of the system (10) leads to the function associated to the positions transfer for the element 7: $\varphi_{71} = \varphi_{71}(s_1)$.

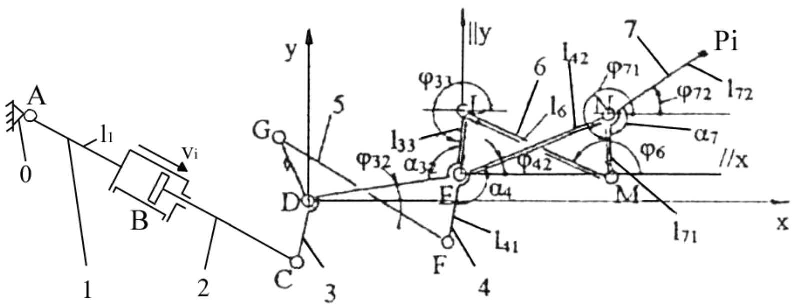


Fig. 8 – Closed ENML vectorial contour.

So, the implicit form for the equation of position is: $\varphi_{72i} = \varphi_{72i}(s_1)$, i – the number of the fingers: $i = 1,2,3,4$.

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

$$v_{Pi} = \dot{\varphi}_{72i}\,, \quad a_{Pi} = \dot{v}_{Pi}\,. \tag{11}$$

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: $v_i \cdot F_i + v_{Pi} \cdot F_{Pi} = 0$. It comes:

$$F_i = -\frac{v_{Pi} \cdot F_{Pi}}{v_i}\,. \tag{12}$$

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 acting between elements.

With the constructive dimensions a 3D model can be obtained using CATIA software. There are two main constructive modules: the support – the palm (see Fig. 9a for three fingers and Fig. 9b for four fingers) and the finger (see Fig. 9c) [11–15].

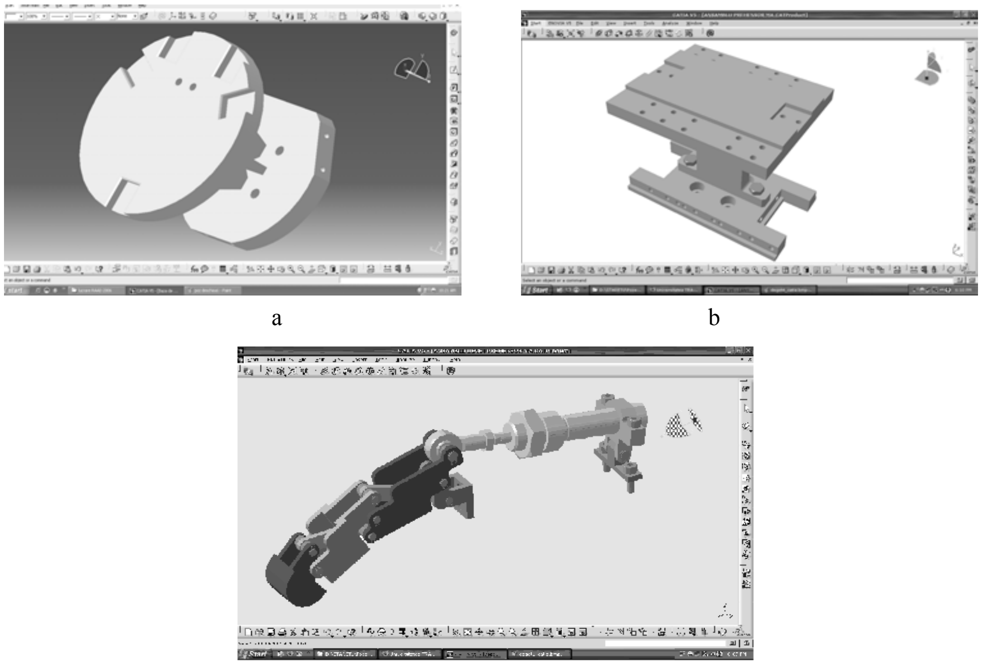


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Fig. 9 – The main constructive modules.

With these modules, four three-finger versions can be obtained (see Fig. 1), from which two are main versions: the fingers having possible parallel (see Fig. 10a) or concurrent movements (see Fig. 10b).

A functional CAD simulation (see Fig. 11) was made to check the correct work and to identify the solutions to obtain the optimum variant for this gripper.

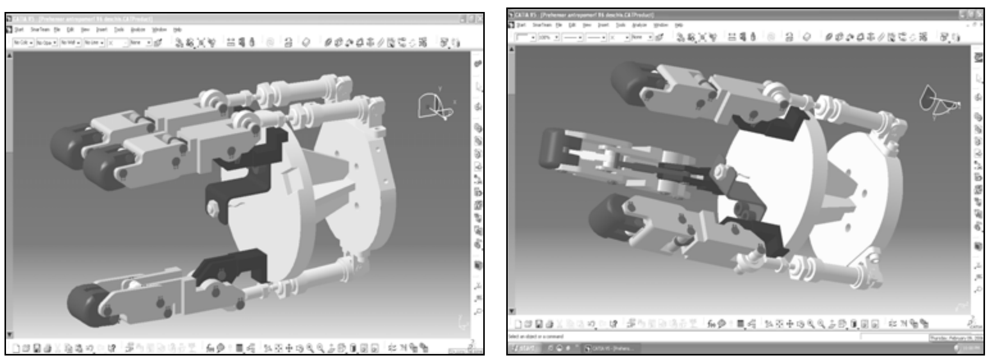

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Fig. 10 – Modular anthropomorphic grippers with three fingers.

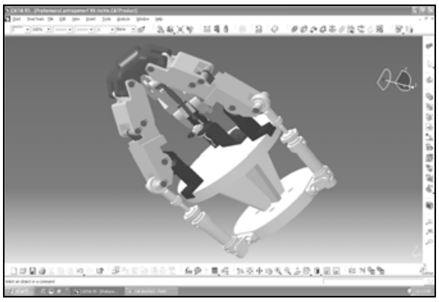
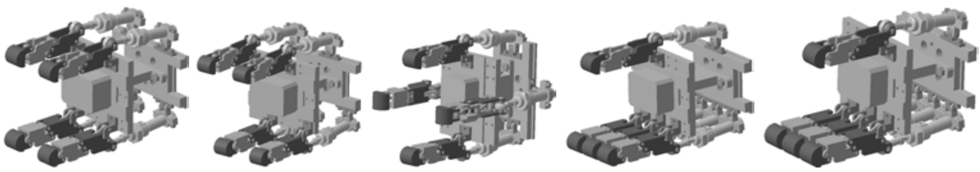


Fig. 11 – The CAD functional simulation.

With the same finger and the second platform, five four-finger versions can be obtained (see Fig. 1b and Fig. 12a): one variant with fingers with parallel axes; one variant with fingers with parallel axes but with an interval; crossing axis; three fingers with one in opposite and central position and three fingers with one in opposite and lateral position. The CAD models of these versions are shown in Fig. 12a. CAD simulations without piece are shown in Fig. 12b and CAD simulations with one grasped piece are shown in Fig. 12c.



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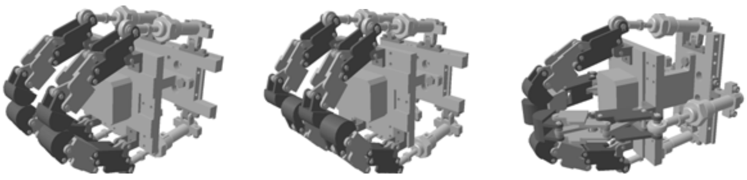

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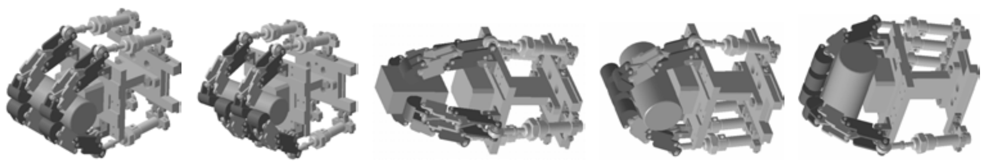

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Fig. 12 – Modular anthropomorphic gripper with four fingers.

These grippers, with one specific intermediary piece, can be mounted on any industrial commercial robot (see CAD simulation in Fig. 13). One of its configurations can be obtained, during the gripper is mounted on robot, only by changing the relative position of the fingers, 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 software (see Fig. 14). 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.

Fig. 13 – CAD example with the gripper mounted on robot.

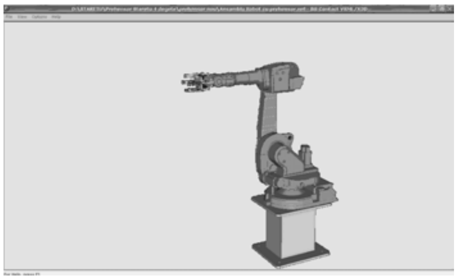

Fig. 14 – The robot with gripper in VRML software.

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 proposed (see Fig. 15a). In Fig. 15b, 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: 140×140×100 mm.

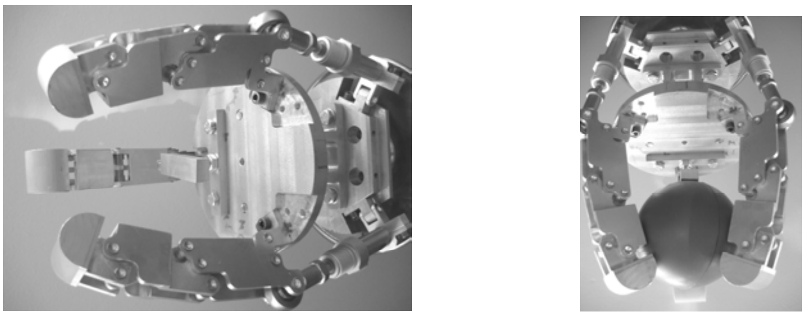

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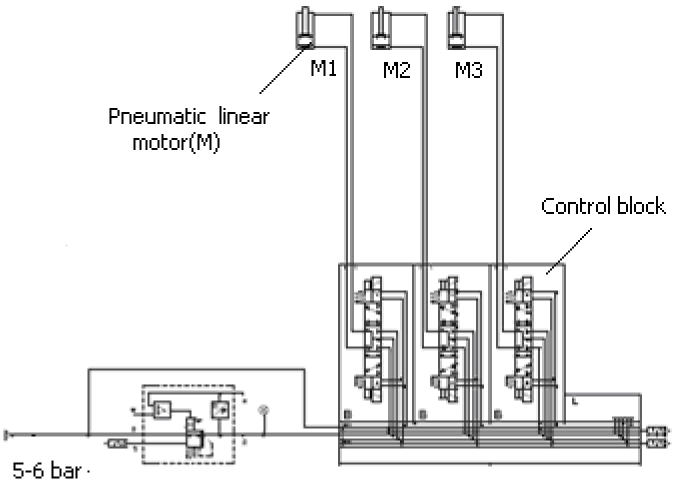
Fig. 15 – Modular anthropomorphic reconfigurable three-fingered gripper prototype.

For the drive, pneumatic linear motors are used. One actuated scheme for three fingers is shown in Fig. 16a and for four fingers in Fig. 16b. 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 anthropomorphic gripper is shown in Fig. 17, 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 in this scheme, requires the use of modular distributors of CPE14-M1BH-5/3B-QS-6 type, and the command and distribution system contains the following sub-assemblies: throttles (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).



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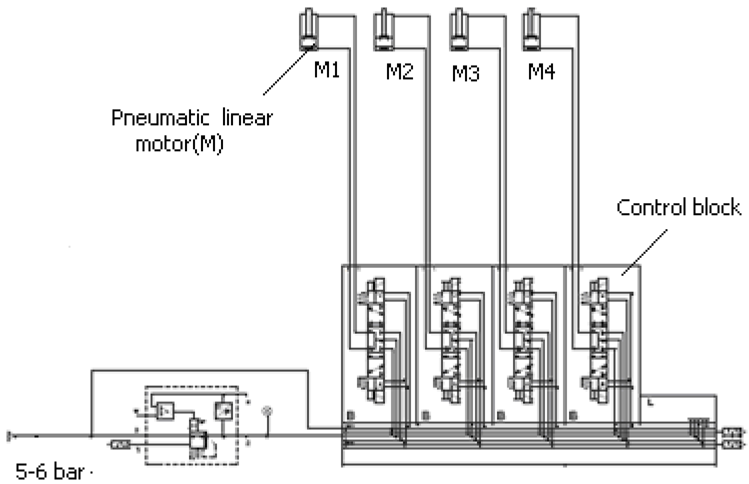

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Fig. 16 – Actuated pneumatic scheme.

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

– issue start signal to close gripper (it can be vocal, electrical, electro-mechanical);

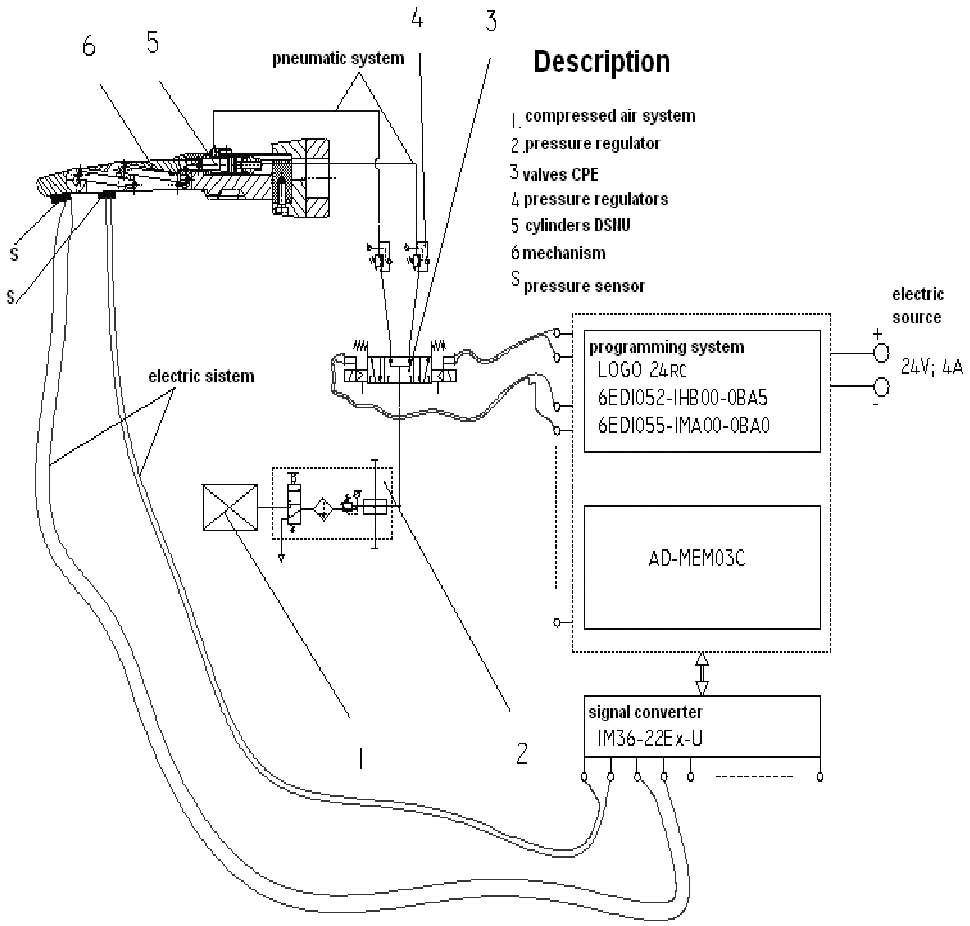

Fig. 17 – The command scheme.

– 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: $F_i = 0$ (example: 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 CZN-CP15 type sensors, 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 converter 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 (see Fig. 13), 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. CONCLUSIONS

According to the considerations presented, the following conclusions can be formulated:

a. In order 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, which can be obtained in accordance with the number and the relative position of the fingers.

c. The grippers with three and four fingers can be obtained using two main modules: the support – the palm, one for each type of gripper and the finger, one type only. With these two modules can be obtained any variants with three, with four fingers and with two fingers too (eleven versions).

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

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