MODULAR ANTHROPOMORPHIC GRIPPERS – STRUCTURAL SYNTHESIS, ANALYSIS AND DESIGN

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Abstract:

In general, anthropomorphic grippers for robots are similar to the human hand and they can have two, three, four or more fingers, with two or three phalanxes. Anthropomorphic grippers for robots compared to other mechanical grippers have more advantages such as: a higher degree of dexterity, a larger area of utility (more types of objects can be grasped) and a micro-movement of the grasped objects can be performed. This paper describes two groups of anthropomorphic grippers for robots: traditional mechanical anthropomorphic grippers and modular mechanical anthropomorphic grippers designed under the author's coordination. For the first group, more versions with two, three, four and five fingers are shown and for the second group, there are more modular solutions shown. The stages of synthesis, analysis, design, and functional simulation are briefly shown as well.

Key words: *anthropomorphic gripper, modular gripper, structural synthesis, cinematic analysis, functional simulation, virtual simulation.*

Introduction

Gripping systems are complex mechatronic systems used by robots, especially by industrial robots, in order to perform gripping operations on different pieces, to handle and transfer them from an initial position to a final one that is associated with a robotised action or technological process. According to the gripping force type, the main categories of gripping systems are mechanical systems, vacuum systems and magnetic systems (Fan, 1982), (Kato, 1982). Mechanical gripping systems are also known as bilateral systems because the grasp is performed using at least two opposite forces onto the piece that is gripped. Mechanical gripping systems have as a main component a mechanical structure, a mechanism that provides the arrangement of the piece's contact elements towards the piece and enhances the contact force that is the necessary gripping force. According to the constructive features of the mechanical structure, there are three main types of mechanical gripping systems: with jaws, with fingers (anthropomorphic) or with tentacles (Doroftei, 2005-2006), (Itu, 2010), (Staretu, 2010), (Staretu, 2011). Nowadays, industrial robots use especially mechanical gripping systems with jaws, but anthropomorphic ones have become more and more popular (see Fig.1), as simple shaped pieces grasp is replaced by a grasp and micro handling of complex shaped pieces (Kato, 1982), (Staretu, et al., 2001).

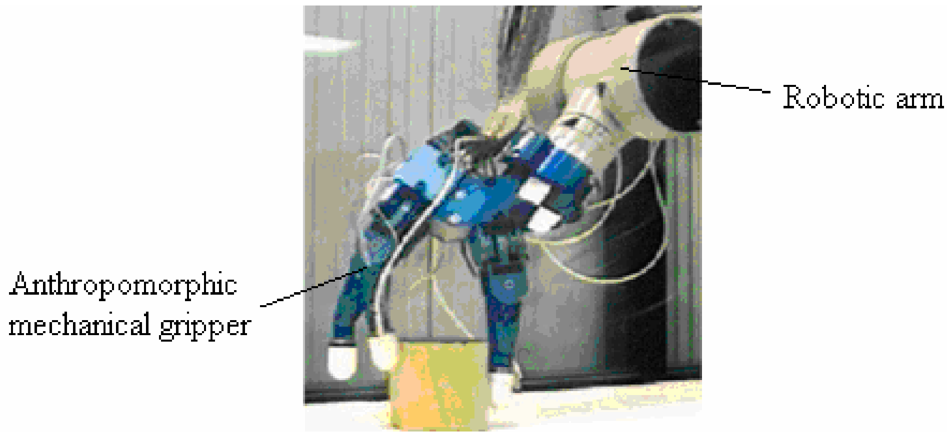


Figure 1 – Industrial robot equipped with anthropomorphic mechanical gripping system
Slika 1 – Industrijski robot s antropomorfnim mehaničkim sistemom za hvatanje
Рис. 1 – Промышленный робот, оснащеный антропоморфной механической системой захвата

Anthropomorphic mechanical gripping systems with fingers can have two, three, four, five, or even six fingers with joints, having two or three phalanxes. This paper describes two categories of anthropomorphic mechanical grippers, traditional and modular with jointed fingers, manufactured based on jointed bar mechanisms-linkages, more simple and with acceptable functionality like a good alternative to a very complex anthropomorphic mechanical hand with very high cost (Kawasaki, et al., 2002); (http://www.barrett.com, 2014); (http://www.shadowrobot.com, 2013); (http://www.bebionic.com, 2013), what there are in present on the market.

Anthropomorphic mechanical grippers

General aspects

In the mechanisms of prostheses, kinematic items most commonly used are articuleted bars-linkages (Belter, et al., 2013). They are found primarily in the construction of fingers. For the rest of the mechanism, in addition to the mentioned elements, common mechanism elements of general mechanical transmission (gears, cams), usually smooth mechanical transmissions, are used (Staretu, et al., 2001). Peculiarities of the optimization for elements and couplings used in the robot gripping anthropomorphic mechanisms are arising from their structural features and construction in the number of fingers, as well as in the number and relative position of the phalanges (Mason, et al., 1985), (Salisbury, et al.,1983). In terms of optimizing the elements, because there may be more than three finger phalanxes, they must be very flexible but resistant, with similar or even identical forms. The results obtained by design optimization are used.

In the optimization of couplings, in addition to the poly-couples use, the adoption of various structural forms no longer limited by the size of the model hand is envisaged, as for the prostheses mechanisms.The phalanges that compose fingers can have the same size, a different relative size or a size that is proportional to the hand fingers size. Concerning the relative positioning of fingers, it can be similar to the human hand; fingers can be placed in one plane, or in different planes. The relative position, depending on the number of fingers, at least two, must be chosen so that their access space is maximal. Several possible versions of relative positioning are illustrated in Fig. 2, out of which it is very easy to obtain 3D fingers arrangement versions (Staretu, et al., 2001), (Staretu, 2010).

From the mobility degree point of view, all the fingers are usually actuated independently; therefore, the mobility degree equals the number of fingers.

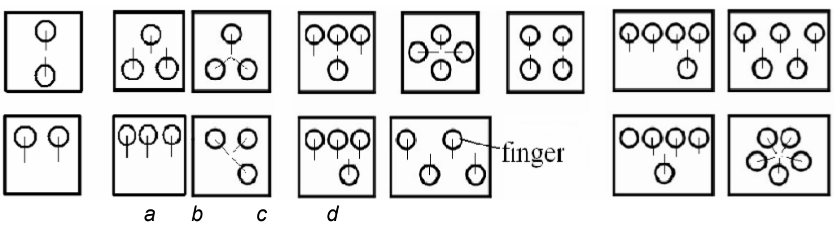


Figure 2 – Relative positions of the fingers
Slika 2 – Relativni položaji prstiju
Рис. 2 – Возможные положения пальцев

In Fig. 3, there are fingers of three, four and five phalanxes derived from e one structural module mechanism. It is represented by the plane anti-parallelogram mechanism.

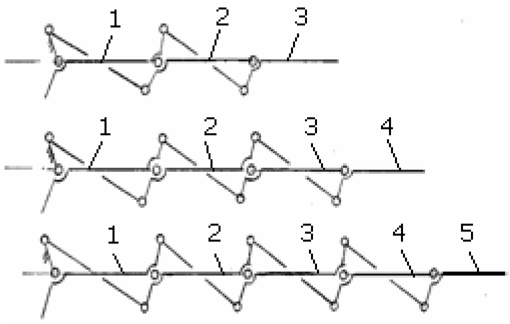


Figure 3 – Modular fingers
Slika 3 – Modularni prsti
Рис. 3 – Модульные пальцы

Structural and cinematic synthesis and analysis

In the case of these mechanical grippers, the finger (Fig.4) is made by connecting more jointed bar mechanisms - linkages, in general anti parallelogram ones, according to the number of phalanxes (two or three) (Staretu, 2008).

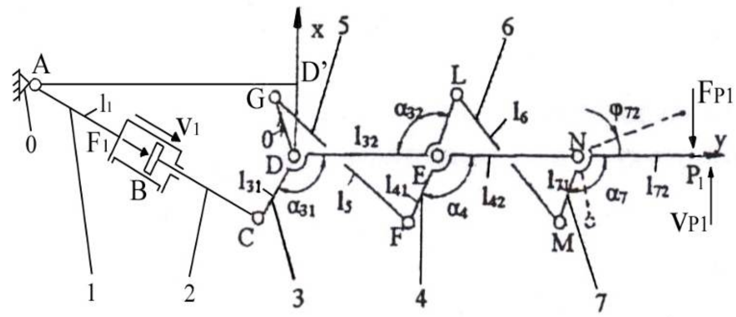


Figure 4 – The structural scheme of a finger
Slika 4 – Strukturna šema jednog prsta
Рис. 4 – Схема структуры пальца

First, through the **structural synthesis,** the configuration of the finger is established, i.e. the driving mechanism type, the number of phalanxes and the number of anti parallelogram mechanisms connected.

During the following stage, the **structural analysis** is performed in order to check if the mechanism is defined from the operational point of view (the mobility degree is determined, the cinematic and static parameters that are independent are identified, as well as the functions that convey external movements and forces).

For the mechanism shown in Fig.4, the mobility degree for each mono-contour mechanism is determined using the formula (Staretu, et al., 2001): $M_k = \sum f_i - \chi_k$ (where $\sum f_i$ is the mobility degree of the couples - f_i= 1 and χ_k= 3 is the cinematic rank of the mono-contour mechanism k=1, 2, 3). So, $M_1 = f_A + f_B + f_C + f_D - \chi_1$ = 1+1+1+1-3=1, $M_2 = f_D + f_E + f_F + f_G - \chi_2$ =1+1+1+1-3=1, $M_3 = f_L + f_M + f_N + f_E - \chi_3$ =1+1+1+1-3 =1. For the multi-contour mechanism, the mobility degree is determined using the formula: $M = \sum M_k - \sum f_c$ (where M_k is the mobility degree for the mono-contour k mechanism and $\sum f_c$ is the mobility degree of the common couples $\sum f_c = f_D + f_E$=1+1=2.). Therefore, $M = M_1 + M_2 + M_3 - \sum f_c$ = 1+1+1-2=1.

M=1 represents an independent movement (independent speed): $v_1 = \dot{s}_1$ and a function that conveys external force: $F_m = F_m(M_7)$.

L-M =1 means a function that conveys external movement $\varphi_7=\varphi_7(s_1)$ or $\omega_7=\omega_7(v_1)$ and an independent momentum M_7 (generated by the gripping force).

The cinematic synthesis means to adopt linear and angular dimensions necessary for the correct closing of the gripping mechanism, and for the correct relative movements of the fingers, in order to grip a group of pieces given.

The cinematic analysis is performed using the method of the closed vector contour, applied successively to the vector contours corresponding to the mono-contour mechanisms underlined in Fig. 5. For the contour ABCD (Fig. 5a), the vector equation is AB+BC+CD+DA=0, and in a matrix form, the scalar form of the vectors is:

$$AB = l_1 \begin{bmatrix} \cos 0 \\ \sin 0 \\ 0 \end{bmatrix}, \; BC = l_2 \begin{bmatrix} \cos\varphi_2 \\ \sin\varphi_2 \\ 0 \end{bmatrix}, \qquad (1)$$

$$CD = l_{31} \begin{bmatrix} \cos\varphi_{31} \\ \sin\varphi_{31} \\ 0 \end{bmatrix}, \; DA = l_{01} \begin{bmatrix} \cos\varphi_{01} \\ \sin\varphi_{01} \\ 0 \end{bmatrix},$$

In addition, the corresponding scalar system is:

$$\begin{cases} l_1\cos 0 + l_2\cos\varphi_2 + l_{31}\cos\varphi_{31} + l_{01}\cos\varphi_{01} = 0 \\ l_1\sin 0 + l_2\sin\varphi_2 + l_{31}\sin\varphi_{31} + l_{01}\sin\varphi_{01} = 0 \end{cases} \tag{2}$$

This system leads to the position function φ_{31} = φ_{31} (s_1).

According to Fig. 5b, the equation corresponding to the closing of the vector contour in the case of the DEFG mechanism is:

$$\overrightarrow{DE} + \overrightarrow{EF} + \overrightarrow{FG} + \overrightarrow{GD} = \vec{0}\,. \tag{3}$$

That leads to the function that transfers the positions φ_{41} = φ_{41} (φ_{31}, s_1). In a matrix form, the scalar form of the vectors is:

$$DE = l_{32}\begin{bmatrix} \cos\varphi_{32} \\ \sin\varphi_{32} \\ 0 \end{bmatrix},\ EF = l_{41}\begin{bmatrix} \cos\varphi_{41} \\ \sin\varphi_{41} \\ 0 \end{bmatrix},$$

$$FG = l5\begin{bmatrix} \cos\varphi_5 \\ \sin\varphi_5 \\ 0 \end{bmatrix},\ GD = lo\begin{bmatrix} \cos\varphi_0 \\ \sin\varphi_0 \\ 0 \end{bmatrix}, \tag{4}$$

Moreover, the corresponding scalar system is:

$$\begin{cases} l_{32}\cos\varphi_{32} + l_{41}\cos\varphi_{41} + l_5\cos\varphi_5 + l_0\cos\varphi_0 = 0 \\ l_{32}\sin\varphi_{32} + l_{41}\sin\varphi_{41} + l_5\sin\varphi_5 + l_0\sin\varphi_0 = 0 \end{cases} \tag{5}$$

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

According to Fig.5c, the equation associated to the closing of the vector contour of the mechanism ENML is:

$$\overrightarrow{EN} + \overrightarrow{NM} + \overrightarrow{ML} + \overrightarrow{LE} = \vec{0}\,. \tag{6}$$

In a matrix form, the scalar form of the vectors is:

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

$$ML = l_6\begin{bmatrix} \cos\varphi_6 \\ \sin\varphi_6 \\ 0 \end{bmatrix},\ LE = l_{33}\begin{bmatrix} \cos\varphi_{33} \\ \sin\varphi_{33} \\ 0 \end{bmatrix}, \tag{7}$$

In addition, the corresponding scalar system is:

$$\begin{cases} l_{42}\cos\varphi_{42} + l_{71}\cos\varphi_{71} + l_6\cos\varphi_6 + l_{33}\cos\varphi_{33} = 0 \\ l_{42}\sin\varphi_{42} + l_{71}\sin\varphi_{71} + l_6\sin\varphi_6 + l_{33}\sin\varphi_{33} = 0 \end{cases} \quad (8)$$

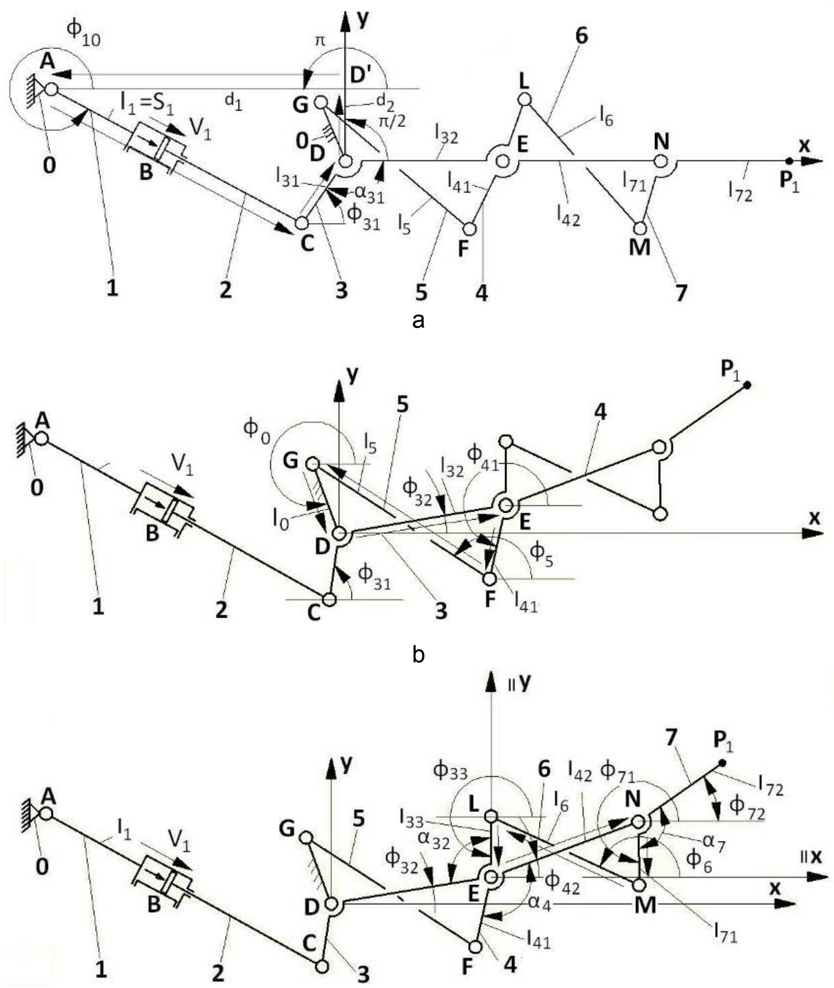


Figure 5 – Cinematic scheme and vector contours

Slika 5 – Kinematička šema i konture vektora

Рис. 5 – Кинематическая схема и векторные контуры

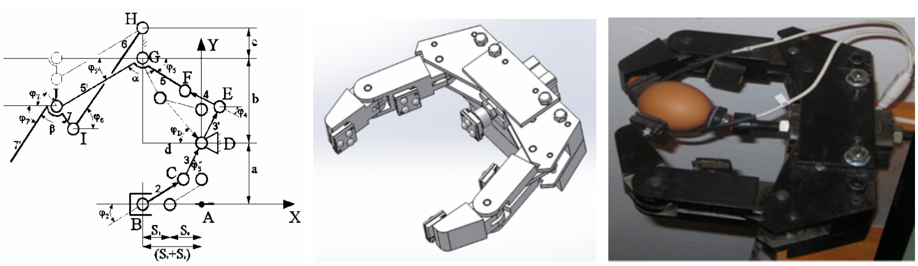
The solution of system (8) leads to the function associated to the positions transfer for element 7: $\varphi_{71} = \varphi_{71}$ (s_1).

Anthropomorphic mechanical traditional grippers

Anthropomorphic gripper with two fingers of two phalanxes

The first anthropomorphic mechanical gripper is a new mechanism, with articulated bars, as shown in Fig. 6. It is made of two identical fingers, each with two phalanxes. The clamping jaws attached to the phalanxes increase considerately the gripping possibilities, turning this simple gripper into a competitive one(Fig. 6b). These jaws can attach to the surface of the gripped object, regardless of its geometry. Each jaw contacts the object in 3 points. This allows the gripper to grasp objects with no matter how complex geometries (Fig.6c). The actuation of both fingers is achieved by using a single motor (Bolboe, 2013), (Bolboe,et al., 2014).

This gripper is powered by one motor Maxon DC, RE 40, Graphite Brushes, and one slew drive reduction gears, of type GP 42 C, 3-15 Nm, Ceramic Version. The sensors used are of anFRS type. The gripper was tested on a complex experimental stand grasping more types of objects. Fig. 6c shows an example of grasping a fragile object(an egg of 0.06 Kg), with a gipping force of 3.76 N per finger(Bolboe, 2013).

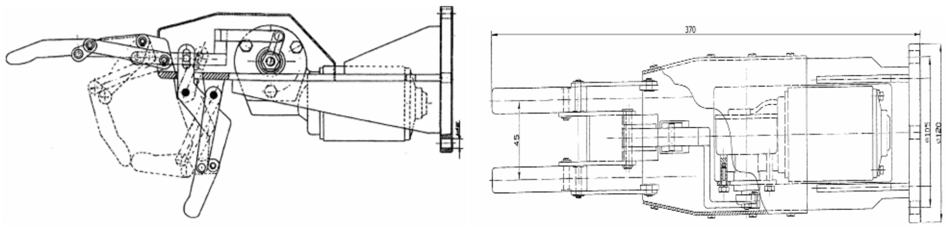


a *b* *c*

Figure 6 – Traditional anthropomorphic gripper with two fingers and two phalanxes
Slika 6 – Tradicionalna antropomorfna hvataljka s dva prsta i dva zgloba
Рис. 6 – Традиционный антропоморфный захват, снабженный двумя пальцами с двумя фалангами

Anthropomorphic gripper with three fingers of two phalanxes

This second version corresponds to a mechanism with three identical fingers, with two articulated phalanxes. The fingers are arranged in an isosceles triangle tops. The mechanism is monomobile and is powered by an electric current minimotoreductor. To close the mechanism, the motor rotates in one direction and for opening, in the opposite, being duly controlled for this purpose. In Fig. 7, there is the drawing of the whole mechanism (a side view and a partially sectioned view from the above).



a b

Figure 7 – *Traditional* gripper with three fingers and two phalanxes
Slika 7 – Tradicionalna hvataljka s tri prsta i dva zgloba
Рис. 7 – Традиционный захват, снабженный тремя пальцами с тремя фалангами

Based on this mechanism, changes in the number of fingers (fingers are identical), can easily result in versions with two, four, five or six fingers. This observation is generally valid if the fingers are of the same type.

Anthropomorphic gripper with four fingers of three phalanxes

This gripper has the structural scheme corresponding to the finger represented in Fig. 8. The gripper has four identical fingers, each with three phalanxes, driven by a linear pneumatic motor located in the palm (Fig. 9).

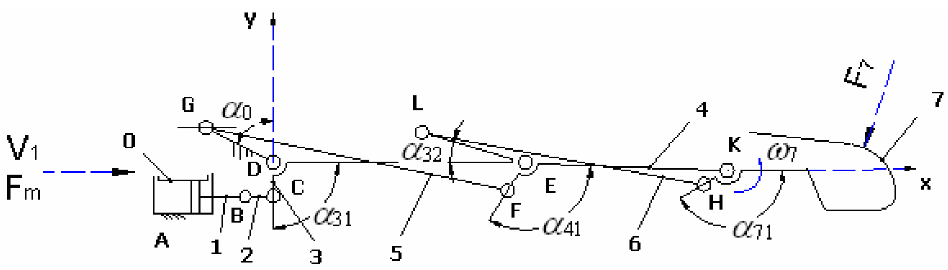
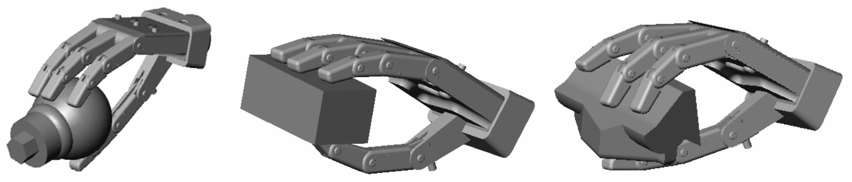


Figure 8 – Structural scheme of the 4-finger gripper
Slika 8 – Strukturna šema hvataljke s četiri prsta
Рис. 8 – Схема структуры захвата с четырьмя пальцами



a b c

Figure 9 – Traditional anthropomorphic gripper with four fingers and three phalanxes – with different grasped pieces

Slika 9 – Tradicionalna antropomorfna hvataljka s četiri prsta i tri zgloba drži predmete različitih oblika

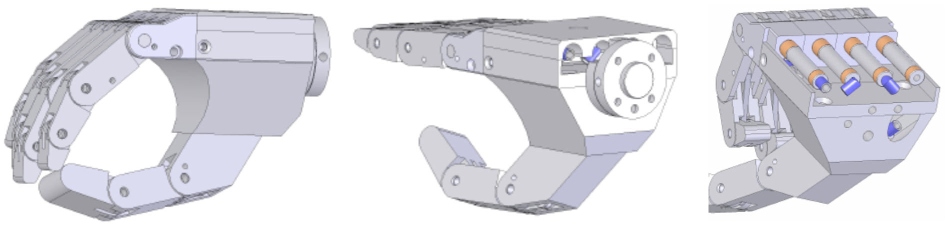
Рис. 9 – Традиционный антропоморфный захват, снабженный четырьмя пальцами с четырьмя фалангами, приспособленный к различным формам предметов

As a result, the gripper has four DOF (M = 4) and can grip any-form parts (Fig. 9). It is equipped with sensors and needs a corresponding flange.

Anthropomorphic Gripper with Five Fingers of Three Phalanxes

The mechanism corresponding to this gripper has five fingers, four of which are identical or not, and the fourth is opposable to the first two, but based on two phalanxes.The four fingers are collinear, and the fifth is located, in general, between the second and third finger of the four, a position opponents.

One *first* version has a structural scheme of the finger similar to the scheme shown in Fig. 8, and the gripper has five DOF(M=5).The constructive version is shown in Fig. 10 (five pneumatic linear motors are used, see Fig. 10c).



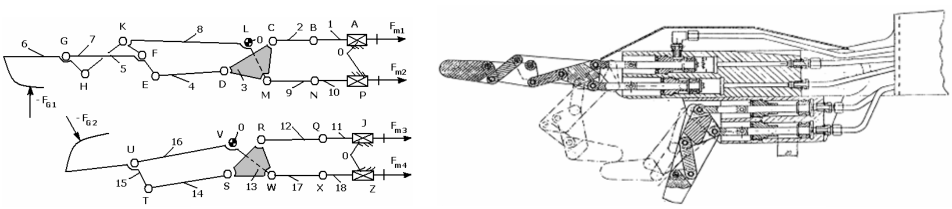
a b c

Figure 10 – Traditional anthropomorphic mechanical gripper with five fingers and three phalanxes- version 1

Slika 10 – Tradicionalna antropomorfna mehanička hvataljka s pet prstiju i tri zgloba – verzija 1

Рис. 10 – Традиционный антропоморфный механический захват, снабженный пятью пальцами с тремя фалангами – версия 1

The structural schemes of one identical finger and an opposable thumb of the *second* version are represented in Fig. 11a. The mechanism is multimobile, having the mobility M = 10 (each of the five fingers is bimobile – it has the degree of mobility M = 2). The fingers are operated for both flexion and extension by two pneumatic or hydrostatic linear micromotors(for example : m1 and m2 or m3 and m4-see Fig. 11a). The opposable thumb pad is adjustable to increase the gripper scope. In Fig. 11b there is the overall drawing of the mechanism (the side view) in which one can identify structural details of the reference above.



a *b*

Figure 11 – Traditional anthropomorphic gripper with five fingers and three phalanxes - version 2

Slika 11 – Tradicionalna antropomorfna hvataljka s pet prstiju i tri zgloba – verzija 2

Рис. 11 – Традиционный антропоморфный захват, снабженный пятью пальцами с тремя фалангами – версия 2

Modular Mechanical Grippers

Modular mechanical grippers designed under the author's coordination are based on two modules, namely: a finger and a base (the palm). Two families that differ in structural features of the finger and platforms were designed. In accordance with Fig. 2, there are four gripping structures (a, b, c, d) obtained by the relative positioning of two, three, four or five identical fingers.

Modular Mechanical Grippers' Family – v1

In this case, the finger's structural scheme in Fig. 12, which is derived from the structural scheme of Fig. 4 was used. The finger has three phalanges and it is driven by a linear pneumatic motor. Using two, three or four fingers and a platform, the versions in Fig. 13 were obtained (Bolboe, et al., 2006), (Staretu, et al., 2006).

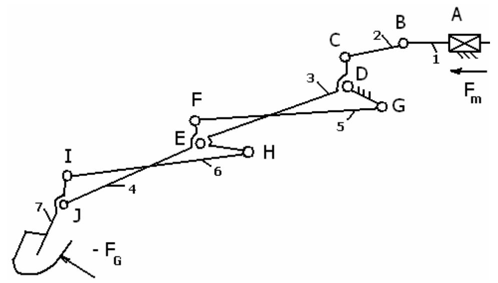


Figure 12 – Structural scheme of a finger for modular grippers – version 1
Slika 12 – Strukturna šema jednog prsta modularne hvataljke – verzija 1
Рис. 12 – Схема структуры пальца модульного захвата – версия 1

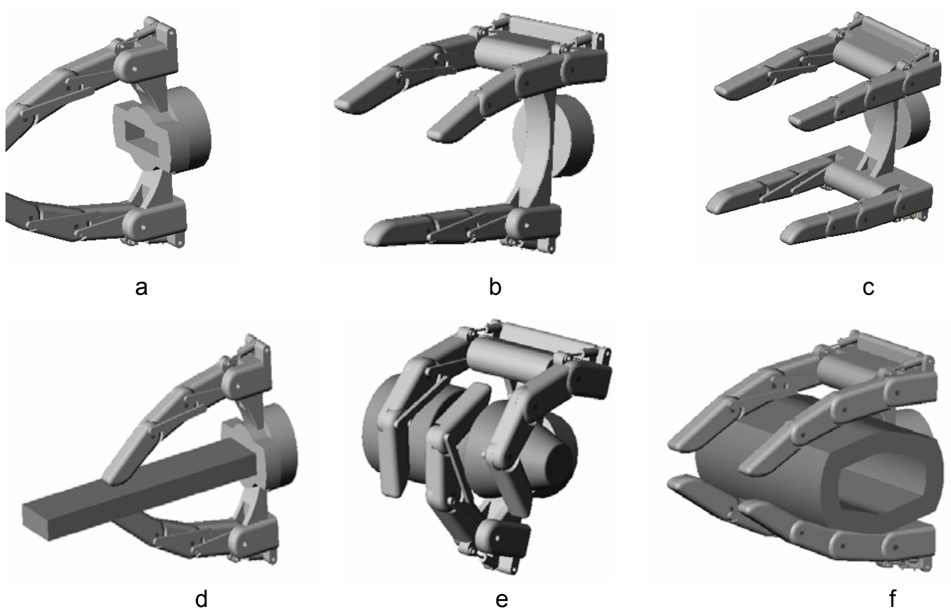


Figure 13 – Modular anthropomorphic grippers family – version 1
(without piece:a,b,c and with grasped piece:d,e,f)
Slika 13 – Porodica modularnih antropomorfnih hvataljjki – verzija 1
(a, b, c bez objekta, d, e, f s uhvaćenim objektom)
Рис 13 – Разновидности модульных антропоморфных захватов – версия 1
(a, b, c без предмета, d, e, f с предметом)

As a result, grippers are bi - tri or tetramobile (M = 2, M 3, M = 4), depending directly on the number of fingers (engine number); they can grip any-shape objects and can be equipped with sensors and an appropriate command and control system compatible with the robot arm that can be fitted with a suitable flange.

Modular Mechanical Grippers' Family - v2

The structural scheme of the finger (see Fig. 4) in this family has the constructive form illustrated in Fig. 14a. Grippers in the family are based on a platform (palm) for three-finger versions (Fig. 14b) and an another platform (Fig. 14c) for four-finger versions(Staretu, et al., 2006), (Staretu, 2008), (Miller, et al., 2004).

With these modules, two main three-finger versions can be obtained (see Fig.2 and Fig. 14), the fingers having possible parallel (Fig. 15a) or concurrent movements (Fig. 15b). In Fig. 15c for the second situation, the gripper closing is simulated and in Fig. 15d a prototype, ready to be tested, is shown.

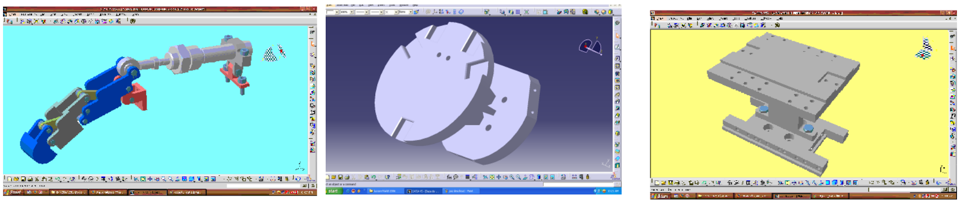


Figure 14 – *Constructive modules*
Slika 14 – Konstrukcioni moduli
Рис. 14 – Конструктивные модули

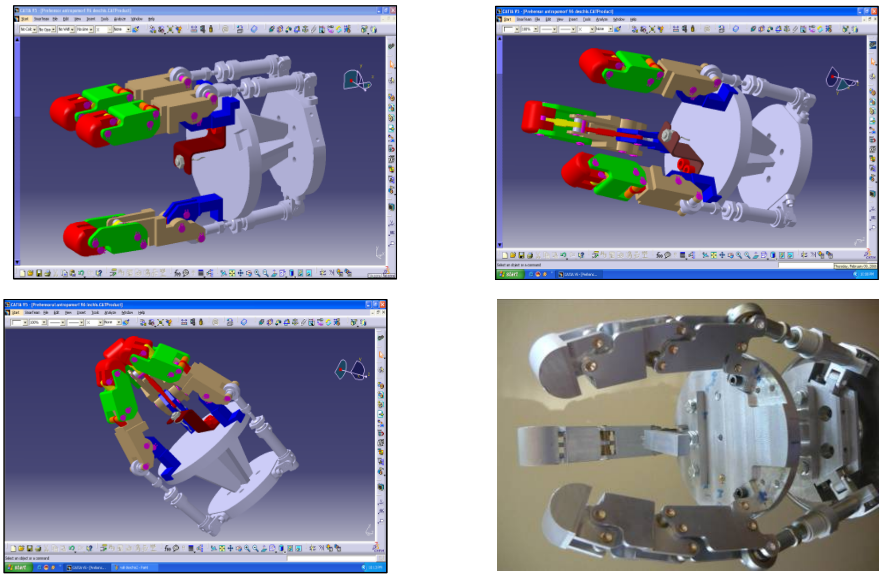
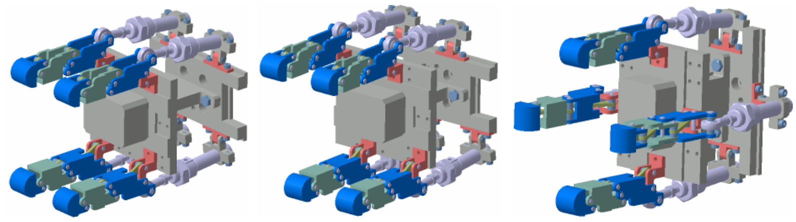


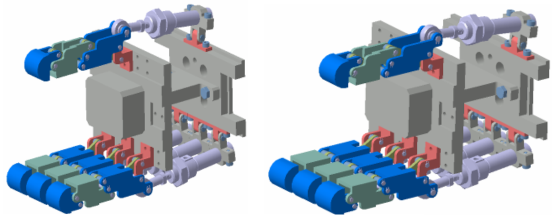
Figure 15 – Modular anthropomorphic grippers' family – version 2, three fingers
Slika 15 – Porodica modularnih antropomorfnih hvataljki – verzija 2, tri prsta
Рис. 15 – Разновидность модульных антропоморфных захватов – версия 2, с тремя пальцами

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: 140x140x100 mm. This gripper has not been tested in practice yet. In the future it will be mounted on an industrial robot and it will be tested for grasping more types of objects.

For a four-finger modular mechanical anthropomophic gripper, there are 5 versions (see also Fig. 2), illustrated in Fig. 16.



a b c



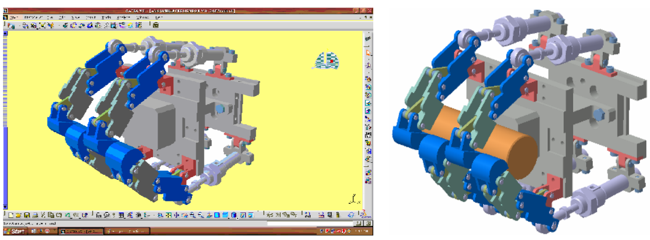
d *e*

Figure *16 – Modular anthropomorphic grippers' family – version 2, four fingers*

Slika 16 – Porodica modularnih antropomorfnih hvataljki – verzija 2, četiri prsta

Рис. 16 – Разновидность модульных антропоморфных захватов – версия 2, с четырьмя пальцами

Fig. 17 illustrates the gripper closing for the fingers intercalated parallel trajectories variants, without any entity to grip (Fig. 17a) and with an entity to grip (Fig. 17b).



a b

Figure 17 – Modular version closing simulation – version 2, four fingers, with no entity to grip (a), with entity to grip (b)

Slika 17 – Simulacija hvatanja modularne verzije hvataljke –verzija 2, četiri prsta, s uhvaćenim objektom (a) i bez uhvaćenog objekta (b)

Рис. 17 – Симуляция захватывания предмета антропоморфным захватом четырьмя пальцами – версия 2. (a) с предметом (b) без предмета

Each finger is actuated by a pneumatic linear motor so that the degree of mobility of the grippers equals the number of fingers. Contact sensors are provided for the fingers, mounting them on the phalanges, and appropriate control equipment is used. Grippers can be mounted on the robot arm through the flange at the platform base and they use the robot's sources of energy. Changing the gripper configuration (depending on the range of parts to grip) is possible without the gripper disassembling, only by changing the finger or the finger's position. With these grippers' families, a variety of parts can be gripped and they can successfully replace more sophisticated and highly expensive anthropomorphic grippers(http://www.barrett.com). Obviously, out of the two basic versions, based on three or four fingers, variants with two, five and even six fingers can be easily derived.

Conclusions

In according with the ideas described in this paper, the main conclusions are as follows:

1. Anthropomorphic gripping systems (with fingers) are used more and more frequently for industrial robots.
2. There is one main type of anthropomorphic mechanical grippers (with fingers) according to their constructive elements: with jointed bars -linkages.
3. There are two main types of anthropomorphic mechanical grippers, what can be classified in two groups: traditional mechanical anthropomorphic grippers and modular mechanical anthropomorphic grippers.
4. The synthesis and the structural and cinematic analysis of these gripping mechanisms can be done using classic well-known methods popular in the theory of mechanisms, correspondingly adapted.
5. Functional simulation, in CAD software of these gripping mechanisms allows their constructive optimization and their use in order to perform the given gripping operations.

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МОДУЛЬНЫЙ АНТРОПОМОРФНЫЙ ЗАХВАТ – СТРУКТУРНЫЙ СИНТЕЗ, АНАЛИЗ И ПРОЕКТИРОВАНИЕ

ОБЛАСТЬ: механика и машиностроение
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

В данный статье приведено описание антропоморфных захватов, выполненных по модели человеческой руки. Они оснащены как «пальцами», двумя, тремя, четырьмя или более, так и двумя или более «суставами»-фалангами. По сравнению с другими видами механических захватов антропоморфные захваты отличаются большей эффективностью, благодаря возможно-

сти захватывания разнообразных по форме предметов, а также возможности микродвижений этих предметов.

В работе описаны две группы антропоморфных захватов: традиционные механические антропоморфные захваты и модульные механические антропоморфные захваты. Оба вида захватов были разработаны под руководством автора статьи.

В работе подробно представлено несколько версий разработки первой группы, оснащенных двумя, тремя, четырьмя и пятью пальцами, а касательно второй группы представлено несколько модульных решений. Приведен обзор этапов синтеза, разработки и процесса проектирования, а также функциональной симуляции.

Ключевые слова: *антропоморфный захват, модульный захват, структурный синтез, кинематический анализ, функциональная симуляция, виртуальная симуляция.*

MODULARNE ANTROPOMORFNE HVATALJKE – STRUKTURALNA SINTEZA, ANALIZA I PROJEKTOVANJE

OBLAST: mehanika, mašinstvo
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Uopšteno govoreći, antrpomorfne hvataljke za robote slične su ljudskim šakama i mogu da imaju dva, tri, četiri prsta ili više, s dva zgloba ili više njih. U poređenju s ostalim mehaničkim hvataljkama, antropomorfne hvataljke za robote su u prednosti zbog veće spretnosti, veće primenljivosti (više različitih tipova objekata se može uhvatiti) kao i zbog mogućnosti mikro-pokreta uhvaćenih objekata. U radu su opisane dve grupe antropomorfnih hvataljki za robote: traicionalne mehaničke antropomorfne hvataljke i modularne mehaničke antropomorfne hvataljke projektovane pod nadzorom autora rada. Više verzija hvataljki iz prve grupe s dva, tri, četiri i pet prstiju dato je u radu, dok je iz druge grupe prikazano više modularnih rešenja. Ukratko su prikazane faze sinteze, analize, projektovanja i funkcionalne simulacije.

Kjlučne reči: *antropomorfna hvataljka, modularna hvataljka, strukturalna sinteza, kinematička analiza, funkcionalna simulacija, virtuelna simulacija.*

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