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Parametric synthesis of system of transmission of motion to links of anthropomorphic gripper of variable structure

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Abstract. The article is dedicated to issues of designing an anthropomorphic gripper (AG) made from actuating link groups (ALG) possessing kinematics similar to human fingers kinematics. The ALG option with the number of output links exceeding the number of motors is being considered. The general drive of links using motion transmission system (MTS) of variable structure is realized. The accepted method of MTS construction provides development of a new feature that is adaptability of the location of links to the profile of the grasped object surface. MTS may be constructed using leverage, rope and combined mechanisms. The transmission of high force is realized by leverage mechanisms. Its special feature is significant number of projected parameters. It determines the necessity of solving a problem of MTS parametric synthesis in optimization performance. The maximal force on the ALG output links at the end positions is proposed to be used as an optimality criterion. The restrictions placed on an optimality criterion and terms of similarity to finger phalanges motion are determined.

1. Introduction

The amount of work executed by robotic systems (RS) under extreme conditions is being expanded permanently [1]. The application of RS in outer space [2-5], under water [6], in emergency zones [7] is the most advanced. All objects of the RS interaction are initially adapted according to parameters and capacities of a human hand.

The Robonaut 2 reproduces astronaut activities on International Space Station [8]. Russian analogue FEDOR is preparing to perform similar functions [9]. Flight missions of space-performed robots correspond to the tasks performed by cosmonauts in full measure.

RS interacts with external objects adapted to kinematic and force capacities of a human hand. This fact determined a new direction of designing gripper devices that are anthropomorphic grippers (AG). AG realizes kinematics similar to a human hand. The gripper includes no less than three independent actuating link groups (ALG). To provide the required kinematics ALG must include three output links and possess three degrees of freedom with parallel axes of rotation. In the general case AG has from 9 to 15 degrees of freedom. According to the classic scheme with providing motion along each degree of freedom from individual motor the technical problems with their placement may appear [10].

Usage of group drive makes it possible to decrease the total number of motors in three times [11, 12]. However, the availability of kinematic dependence of motion of output links leads to decrease of reliability of keeping objects. It caused by the fact that only one or two links contact with object.



Usage of conceptually new approaches of MTS construction in a group drive makes it possible to eliminate that disadvantage. Transmission of motion from a motor to output links is performed by mechanism of variable structure. In this case the adaptability principle of location of links to object surface profile is realized. The basics of construction of ALG of variable structure are represented in previously performed works [13, 14].

2. Scheme of ALG of variable structure of MTS

2.1 Work of system of transmission of motion to the ALG links of variable structure

According to technical decision [12] MTS provides the rotation of three ALG output links from one motor. The peculiarity of the developed MTS is introduction of two additional connections of functioning that provide variability of structural scheme of the whole ALG [13] into a structural scheme. This makes it possible to receive a new feature that is adaptability of the location of ALG output links 1-3 to the object surface (figure 1).

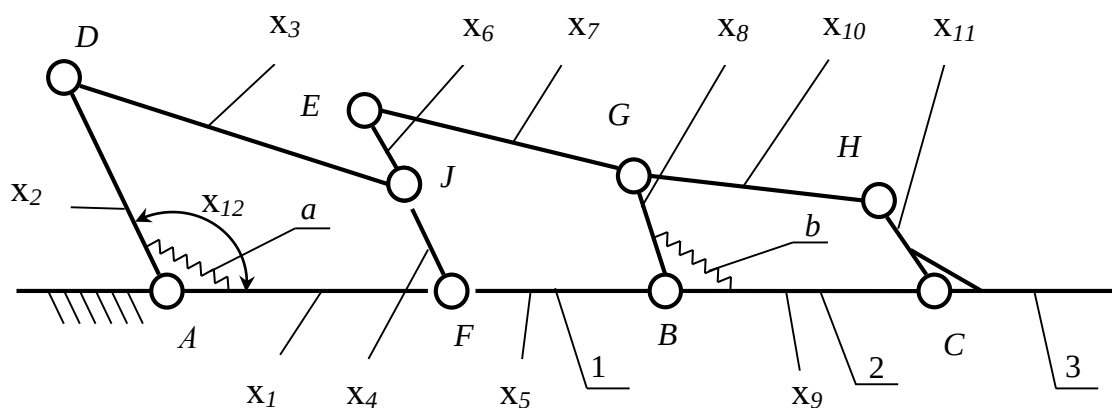


Figure 1. The general kinematic scheme of ALG and its parameters determining the lengths of MTS links $x_1 = l_{AF}$, $x_2 = l_{AD}$, $x_3 = l_{DE}$, $x_4 = l_{FJ}$, $x_5 = l_{FB}$, $x_6 = l_{FE}$, $x_7 = l_{EG}$, $x_8 = l_{BG}$, $x_9 = l_{BC}$, $x_{10} = l_{GH}$, $x_{11} = l_{CH}$, angles of the initial installation x_{12} – balancing lever AD.

MTS is made as a double-lever mechanism. The output link of the drive is connected with the balancing lever AD. The additional connections of functioning are realized through springs *a* and *b* (figure 1). The spring *a* is installed between the first output link AB and balancing lever AD. The second spring *b* is installed between the second output link BC and balancing lever BG.

Three types of structural scheme are realized in the process of ALG working. In case of absence of interaction with external object the motion only in kinematic pair A is provided – that is the first type. The motion in pairs B and C is blocked by additional connections of functioning *a* and *b* (figure 2, a). When the link 1 reaches the object surface it stops (figure 2, b) and the second type of the ALG structural scheme is realized. The link 2 is output and the motion in kinematic pair B is provided (figure 2, b). When it reaches the object surface the third type of the ALG structural scheme is realized. The link 3 is output and the motion in kinematic pair C is provided (figure 2, c).

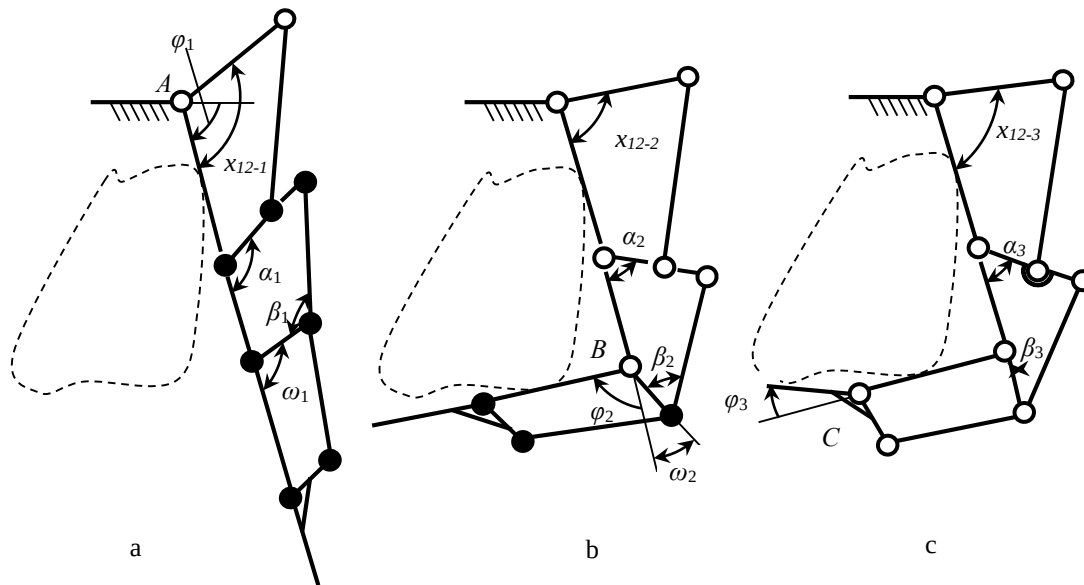


Figure 2. The limit position of angles of relative rotation of output links: a) link 1, b) link 2, c) link 3.

2.2 Projected parameters

Independent projected parameters are lengths of MTS links x_i ($i = 1 \dots 11$) and angle x_{12} of installation of a balancing lever AD (figure 1). This set of parameters determines the location of links definitely.

The number of projected parameters makes twelve units. To calculate projected parameters, it is necessary to have the same number of equations of constraints. If this condition is not fulfilled it is necessary to solve a problem of parametric synthesis in optimization performance.

The direct restrictions of $d_i \leq x_i \leq e_i$ kind, where d_i , e_i are correspondingly min and max accepted values of x_i parameter are imposed upon projected parameters.

2.3 Condition of constraint

Flexibility of a finger interacting with external objects is provided by limit angles of relative rotation of phalanges: 90° for proximal, 135° for medial, 45° for distal. Anthropopathy of grasping determines kinematics of ALG that is similar to the human finger kinematics. In this regard the limit angles of relative rotation of output links must be provided as $\varphi_1 = 90^\circ$, $\varphi_2 = 135^\circ$, $\varphi_3 = 45^\circ$. The rotation of output links by the given angles is provided by projected parameters that is represented by equations of constraint

$$\varphi_2 = f_1(x_i) = 135^\circ \quad (1)$$

$$\varphi_3 = f_2(x_i) = 45^\circ \quad (2)$$

where x_i ($i = 1 \dots 12$).

Besides that, projected parameters must provide the initial position of output links corresponding to the position of phalanges of an open palm $\varphi_2 = \varphi_3 = 0$. This allows to get two more equations of constraint

$$\varphi_2 = f_3(x_i) = 0^\circ \quad (3)$$

$$\varphi_3 = f_4(x_i) = 0^\circ \quad (4)$$

The rotation of link 1 is provided without MTS links concern. It excepts the presence of equations of constraint between φ_1 and x_i .

The number of functional equations of constraint is less than number of projected parameters. The problem of its determination should be solved in optimization performance.

2.4 Optimality criterion in MTS parametric synthesis

The functioning of ALG of variable structure [14] is characterized by two factors: realized angles of relative rotation of links and generated forces while grasping objects. Both factors should be taken into account in solving a problem of parametric synthesis.

When the link 1 of a kinematic pair A rotates the first type of structural scheme is realized. The relative motion of the MTS links is absent. The force applied by output links to external object is determined only by a moment made on a balancing lever AD and does not depend on projected parameters.

When the second type of structural scheme is realized the motion in four-link chains $ADJF$ and $FEGB$ takes place. The force made by link 2 is determined by angle β (figure 1, 2). The maximal degree of transmission of force between links EG and GB is provided when $\beta = \pi/2$. However, the value β changes when angle φ_2 changes. The combination of projected parameters wherein the current value β verges towards $\pi/2$ within the whole period of existence of the second type structural scheme should be considered as optimal. The achievement of function F_1 its minimal value corresponds to this requirement

$$F_1 = \min (k_1 |\pi/2 - \beta_1| + k_2 |\pi/2 - \beta_2|) \quad (5)$$

β_1 and β_2 are angles of links EG and GB correspondingly when $\varphi_1 = 0^\circ$ and $\varphi_2 = 135^\circ$;

k_1 and k_2 are coefficients determining the degree of priority of making force correspondingly at the beginning of the motion of link 2 ($\varphi_2 = 0^\circ$) or at the end ($\varphi_2 = 135^\circ$).

3. Formalization of optimality criterion

The method of closed circuit system [15] is the basis of analytical dependencies.

The final phase of realization of the first type structural scheme (figure 2, a) is represented in equation of constraint (3). The closure condition of the circuit of double-lever mechanisms $FEGB$ determines the following:

$$\beta_1 = \arccos \frac{-l_{EB}^2 + x_7^2 + x_8^2}{2 \cdot x_7 \cdot x_8} \quad (6)$$

where

$$l_{EB}^2 = x_6^2 + x_5^2 - 2x_6 x_5 \cos \alpha_1$$

In its turn angle α_1 is determined from the closure condition of the circuit $ADJF$

$$\alpha_1 = \arccos \frac{x_3^2 - x_4^2 - l_{DF}^2}{2 \cdot x_4 \cdot l_{DF}} + \arctg \frac{-x_2 \cdot \sin x_{12-1}}{-x_2 \cdot \cos x_{12-1} + x_1} \quad (7)$$

where $l_{DF}^2 = x_1^2 + x_2^2 - 2x_1 x_2 \cos x_{12-1}$.

When the second type of structural system is realized the balancing lever GB moves together with link 2 (figure 2, b). The change of value of GBF angle coincides with the rotation angle φ_2 .

Angle β_2 is determined according to functional dependence of (6) type but for angle α_2 , which in its turn is determined by angle x_{12-2} . The equation of constraint (1) should be used to determine the angle x_{12-2} . Angle of rotation

$$\varphi_2 = \omega_1 - \omega_2 = 135^\circ \quad (8)$$

The closure condition of four-link chain $FEGB$ determines the following

$$\omega_1 = \arccos \frac{x_7^2 - x_8^2 - l_{EB}^2}{2 \cdot x_8 \cdot l_{EB}} + \arctg \frac{-x_8 \cdot \sin \alpha_1}{-x_8 \cdot \cos \alpha + x_9} \quad (9)$$

ω_2 is expressed after substituting ω_1 in the dependence 8, then angle x_{12-2} and β_2 are expressed.

Analytic expression of angle β_2 has complicated, multilevel form and is not considered in the article. After substitution of the obtained expressions β_1 and β_2 into the dependence (5) the criterion of optimality is finally formed.

4. Conclusions

The analytical form of representation of functional dependence between MTS projected parameters has been obtained. On its basis the methodology of performance of parametric synthesis providing maximal force transmitted to the output links within operating angle of rotation has been developed.

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