Method of adaptive gripper drive control signal formation

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Abstract. Anthropomorphic gripper is basic component of anthropomorphic robots determining its functionality. Structural scheme provides reliable interaction with nondeterminate external objects. Each actuating system has three output links realizing three degrees of freedom. Movement through individual motors increases gripper dimensions. It determined designing of new type grippers with group drive in actuating system. Interaction between actuating system and external objects realizes in two stages: grasping and holding. In grasping the links execute motions consequently from proximal to distal, output parameters are angles of their relative rotation. Control is performed according to open circuit. actuating system can grasp external objects in nine ways. In holding the output parameter is a force created by the last link got in touch with external objects. Formation of control signal for closed loop control realization includes: registration of links rotation angles, revelation of output link, formalization of calculated parameters. Then the second stage actions are performed: calculation of reduced moment according to required force on output link, control of moment on motor providing minimization of noncoincidence between actual and indicated value. The first stage operations are common for all anthropomorphic robots constructions. Calculated correspondences of the second stage are determined by individual characteristics of applied motion transmission system.

1. Introduction
Anthropomorphic robots (AR) was formed as an independent rapidly growing technology approach. An ability to perform activities specific to human in dangerous environment determined special interest to this kind of machines [1]. Dynamic researches of AR application in space conditions [2, 3], rescue operations [4], underwater operations [5] are conducted. An ability of AR to interact with external objects (EO) is determined by capacities of its gripper. The generality of human hand created by nature determines the striving of researching to design an analogue that is anthropomorphic gripper (AG). It is either caused by robot’s necessity to interact with external objects initially oriented to kinematic and force parameters of a human hand.

The unique capacities of human hand are determined by its structural scheme, the number of mobile links, degrees of freedom, realized parameters: relative rotation angles from 45 to 110 degrees [6], the force made at the ends of the phalanges up to 60 H [7,8]. The given set of parameters should be considered as technical requirement for the designed AG.

All leading robotic centres are concerned in AG designing. AG are built with structural schemes which differs according to the number of: parallel actuating systems – from three to five [9-11], output links in each actuating system (AS) – two, three links [12, 13], degrees of freedom in AS – from two to four [14-16].
AG differs according to the generality: basic level and developed one. Grippers of basic level provide grasping and holding objects with nondeterminate surface. Each AS includes three links \((i=1\ldots 3)\) and three degrees of freedom with parallel axes of rotation. AG of developed level additionally is able to change the orientation of EO. The increase of the level is provided by two ways. According to the first one the additional mobility is entered in the AS joint of the connection with base (with the rotation axe perpendicular to the others). In the second way the rotation of the AG base is realized.

AG of the basic level has from nine to fourteen degrees of freedom [17, 18]. The maintenance of the motion along each mobility from the individual motor is problematic. It is caused by difficulty of arrangement of motors on the base of a gripper or a previous link of the manipulator [19]. In this situation application of group drives of special construction and adaptive control of output links is the most prospective [20-24]. The sequential motion of the AS links starting from the proximal \((i=1)\) is performed from one motor. Each following AS link becomes output if the previous link on the EO stops or reaches the limit relative rotation angle \(\varphi_{3K}\). In each moment of time the only one AS link is output.

2. Interaction of AS and nondeterminate EO

While EO grasping is performed the final values of angles \(\varphi_i (i=1\ldots 3)\) are not fixed parameters and they are determined by the condition when the links reach the EO surface. The law of \(\varphi_i\) variation does not influence the process of EO grasping and does not require monitoring. The control of the movement is performed according to open circuit. The process of grasping ends when all the links stop on the EO surface or the limit angle \(\varphi_{3K}\) is reached.

When the EO is hold the moment developed by the motor makes the AS links produce the controlled force \(R_i\) on its surface. At this stage the closed loop control system is used. The output parameter \(R_i\) can be registered directly on the output link. However, dimensions of the links and kinematic pairs of AS do not allow to arrange the force-torque sensors and realize this method.

The moment from the given force \(R_i\) reduced to the motor shaft \(T_{PD}\) at feedback circuit can be used as an alternative approach.

In the general case the location of EO towards the gripper base and parameters are unknown. The grasp can be realized according to one of nine types (figure 1).
Each type is characterized by exceptional combination of relative rotation angles of links $\phi_i$ and $\phi_{iK}$ and output parameter (table 1).

**Table 1. Identification of EO holding types.**

| Values of AS variable parameters | Type of interaction (figure 1) | Output parameter | Controlled object |
|----------------------------------|---------------------------------|------------------|-------------------|
| $\phi_1$ 0 $\phi_2$ 0 $\phi_3$ 0 | a                              | $R_3$            | Link 3           |
| 0 $\phi_{iK}$ $\phi_{iK}$        | b                              | $R_2$            | Link 2           |
| $\phi_{iK}$ $\phi_{iK}$          | c                              | $R_2$            | Link 2           |
| $\phi_{iK}$ $\phi_{iK}$          | d                              | $R_3$            | Link 3           |
| $\phi_{iK}$ $\phi_{iK}$          | e                              | $R_2$            | Link 2           |
| $\phi_{iK}$ $\phi_{iK}$          | f                              | $R_3$            | Link 3           |
| $\phi_{iK}$ $\phi_{iK}$          | g                              | $R_1$            | Link 1           |
| $\phi_{iK}$ $\phi_{2K}$          | k                              | $R_3$            | Link 3           |
| $\phi_{iK}$ $\phi_{iK}$          | l                              | $R_1$            | Link 1           |

Identification of a holding type performed according the table 1 makes it possible to determine:

- controlled object at the stage of EO holding;
- conditions forming the correspondence of output parameter from the relative position of the AS links.

3. **The formation of controlling actions at the stage of EO holding**

3.1. **Consequence of performed procedures**

Procedure of formation of control signal to the motor is performed in two stages. At the first stage (part a of the flow-chart figure 2) the numerical values of angles $\phi_i$ that determine the configuration of AS are fixed. Then the controlled object is determined, it is a link which produces force $R_i$ on the EO surface. The limit value $R_i$ is chosen on the basis of task for interaction with EO. Operations performed at the first stage do not depend on the applied type of arrangement of the motion transmission system (MTS) and they are determined only by parameters of AS and location of EO towards AG.
At the second stage (part b of the flow-chart) the calculation of the value of reduced moment towards the motor shaft in the function of angles of rotation of output links $\varphi_i$ and construction parameters of the applied MTS system is performed. The control of the motor is realized on the basis of comparing of values $T_{PD}$ and current values of the moment realized on the motor.

3.2. Example of formation of reduced moment

When EO is held the force $R_i$ made by the link $i$ on the surface of EO becomes the output parameter, and $T_{PD}$ becomes the parameter that is used in the feedback circuit. The procedure of reduction of force $R_i$ to the motor shaft is determined by the applied MTS. One of prospective constructions of adaptive AG possessing simple kinematic scheme is presented in figure 3, a [23]. The peculiarities of developing and functioning of the given construction are stated in the paper [24].

Parameters that determine $T_{PD}$ are the following: $l_i$ – lengths of AS links, $l_s$ – lengths of MTS links ($s = 4 \ldots 9$), $h_R$ – arm of a force $R_i$, angle of initial setup of input link 4 of MTS $\beta$ (figure 3, a). The consequence of actions performed in formation of the correspondence $T_{PD} = f (R_i, \varphi_i, l_i, l_s, h_R, \beta)$ has the same method for all types of grasping and it is illustrated in relation to the grasping type $b$ (figure 1).

**Figure 3.** Schemes for reduction of force $R_2$: $a$ – initial location of AS links and MTS, $b$ – location of links in the process of EO holding, $c$ - $e$ – stages of $T_{PD}$ formation.
The method of reduction of \( R_2 \) is based on usage of equilibrium equations made for groups of links and separate links if necessary. The final correspondence of the reduced moment is the following:

\[
T_{PD} = \frac{R^i}{16} \cdot h_6 - R^\tau_8 \cdot h_4 - \frac{R^h}{81} \cdot h_5 = (R_2 \cdot h_5 / h_1) \cdot h_6 - (R_2 \cdot h_4 / h_5) \cdot h_4 - (R_2 \cdot h_3 / h_6) \cdot h_5 (1)
\]

Expressions for determination of values \( h_i \) are derived from classical geometry statements based on values of angles \( \varphi_i \), \( \beta \) and lengths of links. The correspondence (1) is the representation of output parameter on the controlled object link 2 of AS and provides formation of noncoincidence signal in a closed loop control system.

4. Conclusions
The main results appeared from the given research:
AG with group dive and adaptive AS control realizes interaction with nondeterminate EO in two stages: grasping and holding. At the first stage the open loop control system is realized. The controlled objects are links sequentially from proximal to distal. At the second stage the closed loop control system is performed, it provides the production of the required force on EO.

AS grasps nondeterminate EO according to one to nine possible types. Identification of the realized type and controlled object is performed according to values of output links rotation angles of AS.

In the process of holding the object it makes sense to use the moment from the given force reduced to the motor shaft as controlled parameter at feedback circuit. The sort of analytic correspondence of the reduced moment is determined by the type of grasping and parameters of AS and MTS.

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