Synthesis of algorithm for stabilization of spatial position of manipulator gripper of parallel structure

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Abstract. Method of synthesis of kinematic algorithm of stabilization of spatial position of manipulator gripper of parallel-serial structure relative to given position is described in work. Coordinates and speeds and accelerations of generalized coordinates of manipulator are taken as control parameters. Analytical ratios of the control signals of the drive electric motors are obtained, which ensure the movement of the working body of the manipulator in the vicinity of the designated point. Numerical examples of the implementation of the obtained control laws are given.

1. Introduction
Manipulators of parallel-sequential structure find application in technological processes, during which high speeds and accelerations of the working element are required. Tripod manipulators are used in the assembly of chips, sorting and packaging of products. The operation time is up to 0.5-2 seconds [1-5]. Invention describes kinematic scheme and structure of manipulator consisting of two series-connected manipulators - manipulator-tripod, parallel structure and manipulator of serial structure. The sequential manipulator plays the role of a gripper. The task is divided into two stages. At the first stage, the configuration of the manipulator in the specified final position is determined. At the second stage laws of variation of generalized coordinates are formed when attachment point of gripping device moves from initial position to specified neighborhood of final state in preset time.

2. Object of research
Manipulator in the form of triangular pyramid with active actuating links of variable length \( l_1, l_2, l_3 \) is considered. One end of these links is connected by means of two movable hinges located on fixed base \( ABC \). Other ends of manipulator links are connected at point \( M \) by means of special spherical hinge assembly [6]. Photo and kinematic diagram of the manipulator under consideration are given in figure 1, 2 [7]. As actuators, links with electric DC drive are used. Actuating links have analogue displacement sensors.

Controlled gripping device consisting of three links connected in series with each other by means of cylindrical hinges is mounted on spherical hinge unit. Generalized coordinates of manipulator are lengths of links \( l(t) \), angles of relative turns of links of gripping device \( \alpha(t), \psi(t), \beta(t) \). The manipulator has six degrees of freedom.
The spatial position of the manipulator grip (figure 1) is determined relative to the $Ox_{yz}$ absolute coordinate system. Movable coordinate systems $Ox_{j}y_{j}z_{j}$, ($j$=1-3) [8, 9] are connected to housing of each actuating link of gripping device.

![Figure 1. Kinematic diagram of manipulator - tripod on fixed base.](image1)

![Figure 2. General view of the manipulator.](image2)

3. Algorithm for synthesizing the laws of moving the grip to a given position

We believe that when implementing the control algorithm, requirements for control accuracy are imposed only on the end point, without imposing restrictions on the trajectory of movement of the characteristic capture point, which is not predetermined. As generalized coordinates of the manipulator we take $q_1 = l_1(t)$, $q_2 = l_2(t)$, $q_3 = l_3(t)$, which describe the tripod configuration. The coordinates $q_4 = \alpha(t)$, $q_5 = \psi(t)$ describe the state of the three-link gripper. Angle $q_6 = \beta(t)$ does not affect the orientation of the working element, and the law of its change is determined by the nature of the technological operation.

For each actuating link, control loops are known, closed by the generalized coordinates $q_i(t)$, $i$=1-6. In this case, the solution of the problem is reduced to the definition of laws for the formation of control actions $q_i(t)$ for actuators that ensure the movement of the working element to a given position.

At the initial time $t=0$, the configuration of the manipulator is known and is characterized by the lengths of the actuating links $q_i(0) = l_{0i}$, $i$=1-3 and the angles $\alpha(0) = 0$, $\psi(0) = 0$, $\beta(0) = 0$. Since the manipulator-tripod has great rigidity, Cartesian coordinates of the characteristic point of the working member are determined through the lengths of the actuating links with great accuracy [10].
\[ x_M = \frac{l_1^2 - l_2^2}{4OB}, \quad y_M = \frac{L}{2OA}, \quad z_M = \left( l_1^2 - \frac{(l_1^2 - l_2^2)^2}{16OB^2} - \frac{L^4}{4OA^2} \right)^{0.5}, \tag{1} \]

\[ L^2 = \left[ -l_1^2 + 0.5l_2^2 + 0.5l_3^2 - OB^2 - OA^2 \right]. \]

At specified coordinates of characteristic point \( M(x_M, y_M, z_M) \) and guiding cosines of gripping device \( \alpha_{pq} \) in assigned point, length of actuating links \( l_i^0 \) and angles \( \alpha, \psi, \gamma \) are located from solution of positioning problem [10]. The method of control system synthesis for laws of change of lengths \( l_i(t) \) of actuating links ensuring movement of grip in vicinity of point with specified coordinates in specified time \( T \) is described below.

\[ \left| l_i^0 - l_i(T) \right| \leq \varepsilon, \]

where \( \varepsilon \) is a small positive number characterizing the specified accuracy.

The angle \( \beta \) does not change, and the laws of forming the stabilization of the angles \( \psi(t) \) and \( \alpha(t) \) are formed according to the same method.

We accept that on the trajectory of motion the deviations from the final state of the actuating links \( \Delta l_i(t) = l_i^0 - l_i(t) \) change in accordance with the solution of the differential equation

\[ \Delta \ddot{l}_i(t) + a_{ii} \Delta \dot{l}_i(t) + a_{zz} \Delta l_i(t) = 0 \tag{2} \]

where \( a_{ii}, a_{zz} \) are constant positive numbers.

Laws of generation of driving effects \( l_i(t) \) of actuators defined by equations (2) correspond to differential equations

\[ \ddot{l}_i(t) + a_{ii} \dot{l}_i(t) + a_{zz} l_i(t) = a_{zz} l_i^0, \tag{3} \]

at initial conditions describing the manipulator state at \( t_0=0 \)

\[ l_i(0) = l_{i0}, \quad \dot{l}_i(0) = \dot{l}_{i0}. \tag{4} \]

The general solution of equation (3) is:

\[ l_i(t) = l_i^0 + C_{1i} e^{p_{1i} t} + C_{2i} e^{p_{2i} t}, \tag{5} \]

where the roots \( p_{1i}, p_{2i} \) are the roots of the respective characteristic homogeneous equation.

Permanent integration is found from (5) taking into account (4)

\[ C_{1i} = \frac{\Delta l_i(0)}{(p_{i1} - p_{2i})} + \dot{l}_{i0}, \quad C_{2i} = -\frac{\Delta l_i(0)}{(p_{i1} - p_{2i})} + \dot{l}_{i0}, \tag{6} \]

where \( \Delta l_i(0) = l_i^0 - l_i(0) \).

The coefficients of equations (3) are determined through the roots of the characteristic equation \( p_{1i}, p_{2i} \)

\[ a_{ii} = -\left( p_{i1} + p_{2i} \right), \quad a_{zz} = p_{i1} p_{2i}. \]

To ensure the requirement \( l_i(t) \rightarrow l_i^0 \) at \( t=T \), the roots of the characteristic equation are negative different. Values of roots of characteristic equation should be selected from permissible parameters of
manipulator mobility [11] (maximum permissible speeds of grip movement in working zone) and
required time of getting to target point with required error.

The law of change of lengths of executive links (5) is program. To construct the control law with
feedback, it is necessary to calculate the operating speedups on the current values of the generalized
coordinates and speeds. In formulas (6) take the current values of the generalized coordinates for
initial values of the generalized coordinates.

\[
\hat{l}_i^*=\left[\frac{\dot{\hat{l}}_i^0-\dot{l}_i(t)}{p_{u_1}-p_{u_2}}\right]p_{u_1}e^{p_{u_0}(T-\Delta T)} - \left[\frac{\dot{\hat{l}}_i^0-\dot{l}_i(t)}{p_{u_1}-p_{u_2}}\right]p_{u_2}e^{p_{u_2}(T-\Delta T)}.
\]

Feedback in control circuits of drive motors is performed by variables \(l_i(t), \dot{l}_i(t)\). The values of these
variables are used to evaluate expressions included in expressions (7). Structural diagram of control
loop corresponding to (7) is given in figure 3.

**Figure 3.** Structural diagram of the control system.

Figure 4, 5 shows the results of calculations when the gripper moves from the position determined
by the coordinates of the point \(E\) \(x_{E0}=88.3\) mm, \(y_{E0}=-6.9\) mm, \(z_{E0}=1073\) mm to the point with
coordinates \(x_{E}=250\) mm, \(y_{E}=-6.9\) mm, \(z_{E}=1300\) mm, \(p_{1}=3\), \(p_{2}=-2\):

**Figure 4.** Laws of change of length of actuating links (Solid line - zero deviations,
dashed line - with initial deviations).

**Figure 5.** Trajectories of capture point M.

### 4. Conclusion

The article proposes an algorithm for terminal control of manipulator gripping. The difference of the
proposed algorithm is to correct the program path so that it passes at each time point through the
assigned point. This method of constructing a program path allows you to automatically adjust the
speed when moving to a given point. The need to correct the program path can be caused by external
disturbances, the problem of weak terminal control is solved. Analysis of the closed system showed that over time the mobile object falls into the final region $\delta_y$ of the target point, however, the magnitude of this region depends on the dynamic properties of the control system.

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**References**

[1] Glazunov V A, Koliskor A Sh and Krainev A F 1991 *Spatial mechanisms of parallel structure* (Moscow: Science)

[2] Bushuev V V and Hol'shev I G 2001 The mechanisms of parallel structure in mechanical engineering *STIN* 1 pp 3–8

[3] Afonin V L, Podzorov P V and Slepcov V V 2006 *Processing equipment on the basis of mechanisms of parallel kinematics* (Moscow: Mashinostroenie)

[4] Liu N and Wu J 2014 Kinematics and application of a hybrid industrial robot Delta-RST *Sens. Transducers* 169(4) pp 186–92

[5] Tanev T K 2000 Kinematics of a hybrid (parallel-serial) robot manipulator *Mech. Mach. Theory* 35(9) pp 1183–96

[6] Gerasun V M, Pyndak V I, Nesmiyanov I A, Dyashkin-Titov V V and Pavlovsky V E 2012 Manipulators for mobile robots. The concept and design principles (*Preprints IPM of M V Keldysha*)

[7] Zhoga V V, Dyashkin-Titov V V, Dyashkin A V and Vorob'eva N S 2017 *RU Patent* 2616493

[8] Korendesev A I, Salamandra B L and Tyves L I 2006 *Theoretical basis of robotics. In 2 books* (Moscow: Nauka)

[9] Kolovskii M Z and Sloushch A V 1998 *Foundations of Industrial Robot Dynamics* (Moscow: Nauka)

[10] Zhoga V V, Dyashkin-Titov V V, Nesmiyanov I A and Vorob'eva N S 2016 Manipulator of parallel-serial structure with a controlled gripper positioning task *Mechatronics, automation, contro.* 8(17) pp 525–30

[11] Hapkina I K 2016 The control algorithm for manipulation robots, built on the equations of dynamics *Izvestija TulGU. Technical science* 2 pp 296-304