Guidance dynamics of the optical load of a multielement manipulator

N E Tochilkin¹, A I Kimyaev¹ and V V Sheval¹

¹ Moscow Aviation Institute, 4, Volokolamskoe shosse, Moscow, 125993, Russia

Abstract. The dynamic equations of a flat motion of the angular-type multielement manipulator are considered; the manipulator has the payload as an image formation device of a mobile observed object. Dynamics constraints of a manipulator-driven load via stepper motors are investigated. Nonlinear control algorithms are suggested for the tracking of an observed object via feedback actuators associations operating as one multicoupling control feedback actuator.

1. Introduction

Tasks of the mobile objects tracking by the visual fields of the carrier-mounted optical devices for an image formation are appeared in many fields of technology. Main quality operation conditions of the control systems (CS) of the observation complexes (OC) with movable carrier are providing constant location of an observed object (OO) in the visual field (VF) of the optical device and clearness of a received image. In control terms, the conditions define the strict requirements to quality indexes (QI) of CSoOCs, such as speed of response, dynamic accuracy in quasi-steady-state modes, and smoothness in the responding to the creep speed. Nontriviality of the assurance of mentioned QIs is that the assurance methods of every QI contradict to ones of other QIs.

One solution of the control problem is considered in [1] for the movable carrier providing the direction of the VF of the onboard device for an image formation. In [1], error signal in the closed-loop system of the mobile OO tracking is automatically generated according to the results of an adjacent frames analysis.

Flat two-element manipulators are used as a mechanical suspension for receiving more informative foreshortenings of the location of the onboard device for an image formation [2], the requirements being the same for the QIs of the VF direction control as for above-mentioned ones.

Also, such tasks of the mobile object observation are solved in the CS with multielement manipulators, in which video camera (VC) is used as an operation tool [3]. Range of tasks solved with such manipulators is wide and can include work with radioactive substances in the isolated chambers, maintenance of the numerical control machines, carrying out high precision three-dimensional measurements, etc.

In synthesizing the CSoOCs of such complex commercial-grade items (OC mounted on movable and static carriers), designer must consider their features:

- combination of relative and bulk motion velocities of the mechanical movements;
- multicoupling of the mechanical part of a controlled element;
- nonstationarity of the parameters of a controlled element;
- nonlinear character of the relations in a controlled element;
- operation of the several feedback actuators (FA) with the same load;
- presence of a delay in the error signal discriminator based on technical analysis of received images.
Choice of the actuation motors significantly influences on the possibility of assurance of the required dynamic characteristics. In many robotics problems, stepper motors (SM) are widely used having noticeable advantages in solving the steady-state control tasks with absence of the additional curve requirements. Primarily, these advantages are provided by absence of feedback in setting only initial and end placement points of a payload. However, one can occur loss of synchronization of set and current steps [4] in operation of the SM with a load; it is unacceptable in CSoOCs where important QIs are dynamic accuracy and speed of response and it consequently leads to introduction the output signals feedbacks of the local FAs. Well-known SM closed-loop control methods are steps verification and registration of the back EMF in the exciting windings [5]. Disadvantages of steps verification are lack of shaft speed control and impossibility of compensation of the steady-state error results from active external forces and torques. The last disadvantage also refers to back EMF registration.

In this paper, one of the new options of path tracking controller design is investigated. The controller provides the following requirements:

- high speed of response (due to criticality of the OC using item even to minimal images losses);
- low error of tracking for OO elements having small-scale structure even in the foreshortening change process (due to criticality of OC using item even to minimal image quality degradation).

### 2. Dynamic equations

In this section, mechanical subsystem of the OC based on a five-degree-of-freedom manipulator (further, controlled element (CE)) with VC as an operating tool is considered. Physical analog of the subsystem is shown in Fig. 1, where $Pr_j, j = 0, 1, 2, 3, 4$ are controlling electric actuators; $OA_{x_0}y_0z_0$ is the fixed (further, absolute) axes system (AS); $OA_{x_0}y_0z_0$ is the local AS related with actuator $Pr_0$. Origins of $OA_{x_0}y_0z_0$ and $OA_{x_0}y_0z_0$ ASs are coincided with the OO, and their vertical axes are coincided with the spin axis of the actuator $Pr_0$ and the local vertical. The vertical motion plane of the CE and $OA_{x_0}y_0$ plane are coincided. Payloads driving by corresponding electric actuators are marked with dotted line contours: I, II, III contours are the loads driving by actuators $Pr_1, Pr_2, Pr_3$, respectively; the load of the actuator $Pr_0$ is the whole moving part of the manipulator, which is marked with rectangular dotted line contour.

As mentioned above, the fidelity of a nonstationary attitude of the VC is especially important in the continuous tracking. Since cross couplings appeared as a result from cooperation of the local FAs [6] significantly influence to the dynamic accuracy in high precision tracking tasks, it is advisable to analyze this impact and to design the correction algorithms for the actuators if it is necessary. Significant importance in the design problems hierarchy is considering the motion of the CE in $OA_{x_0}y_0$ plane. Further, the motion CS of the OC in $OA_{x_0}y_0$ plane will be called a subsystem of the CSoOC (SCSoOC).

Physical analog of the flat representation of the CE is shown in Fig. 2, where $OA_{x_1}y_1$, $i = 1, 2, 3$ are the local ASs related with corresponding electric actuators $Pr_i$; $\theta_i$, $\phi_i^a$ are the relative and absolute rotation angles of the manipulator elements, respectively; $\psi_d$ is the angular foreshortening of the optical axis of the VC; $R_d$ is the slope distance between the VC and the OO.

We will use Lagrange equations of the second kind with relative rotation angles and angular velocities of the elements as generalized coordinates for formulation the equations of the plane motion of the CE:

$$
\frac{d}{dt} \left( \frac{\partial (T_\Sigma - U_\Sigma)}{\partial \dot{q}_i} \right) = \frac{\partial (T_\Sigma - U_\Sigma)}{\partial q_i}, \quad (1)
$$

where $T_\Sigma$ is the kinetic energy of the CE, $U_\Sigma$ is the force function, $q_i = \theta_i$ is the relative rotation angles of the manipulator elements, $\dot{q}_i = \dot{\theta}_i = \omega_i$ is the relative angular velocities of the manipulator elements.
Figure 1. Physical analog of the mechanical subsystem

Figure 2. Physical analog of the plane mechanical suspension of the CE
3. Kinetic energy

The kinetic energy of the CE is defined as the sum of the kinetic energies of the payloads of the corresponding actuators:

\[ T_\Sigma = T_{\Sigma 1} + T_{\Sigma 2} + T_{\Sigma 3}, \]  

(2)

where \( T_{\Sigma 1}, T_{\Sigma 2}, T_{\Sigma 3} \) are the kinetic energies of the payloads of actuators \( Pr_1, Pr_2, \) and \( Pr_3, \) respectively.

Kinetic energy \( T_{\Sigma 1} \) is defined by the rotational motion of the payload of the actuator \( Pr_1 \) around the axis \( o_1 \):

\[ T_{\Sigma 1} = \frac{1}{2} \Omega_1^T J_{\Sigma 1} \Omega_1, \]  

(3)

where \( \Omega_1 = \omega_1 \) is the absolute rotational velocity of the load, \( J_{\Sigma 1} = f(\varphi_2, \varphi_3) \) is the moment of inertia of the load around the axis \( o_1 \).

Load driving by actuator \( Pr_2 \) is involved into complex motion so it is necessary to consider its relative and bulk motion velocities for obtaining the kinetic energy. The velocities are shown in Fig. 3a, where \( CM_{\Sigma k}, k = 2, 3 \) are the mass centers of the payload of the actuators \( Pr_k; R_{CM_{\Sigma k}} \) is the vector between the spin axis of the actuator \( Pr_k \) and \( CM_{\Sigma k}; V_{CM} \) is the linear velocity of \( AS o_kx_ky_k; V_{CM_{\Sigma k}} \) is the linear velocity of \( CM_{\Sigma k} \) movement relative to the \( AS o_kx_ky_k; \Omega_k \) is the absolute rotational velocity of \( AS o_kx_ky_k \) movement.

![Figure 3. Velocity vectors](image)

The kinetic energy of the payload of the actuator \( Pr_2 \) is defined by:

\[ T_{\Sigma 2} = \frac{1}{2} m_{\Sigma 2} \left| V_{o_2} + V_{CM_{\Sigma 2}}^r \right|^2 = \frac{1}{2} V_{o_2}^T m_{\Sigma 2} V_{o_2} + m_{\Sigma 2} \left( V_{o_2} \cdot V_{CM_{\Sigma 2}}^r \right) + \frac{1}{2} \Omega_2^T J_{\Sigma 2} \Omega_2, \]  

(4)

where \( m_{\Sigma 2} \) is the load mass, \( \Omega_2 = \omega_1 + \omega_2 \) is the absolute rotational velocity of \( AS o_2x_2y_2 \) movement, \( J_{\Sigma 2} = f(\varphi_2) \) is the moment of inertia of the load around the axis \( o_2 \).

Analogically, the kinetic energy of the payload of the actuator \( Pr_3 \), which is also involved in complex motion (Fig. 3b), is defined by:
\[ T_{E3} = \frac{1}{2} m_{E3} \left| \dot{V}_{o3} + \dot{V}_{CM_{E3}} \right|^2 = \frac{1}{2} \dot{V}_{o3}^T m_{E3} \dot{V}_{o3} + m_{E3} (\dot{V}_{o3} \cdot \dot{V}_{CM_{E3}}) + \frac{1}{2} \Omega_{E3}^T J_{E3} \Omega_{E3}, \]  

(5)

where \( m_{E3} \) is the load mass, \( \Omega_{E3} = \omega_1 + \omega_2 + \omega_3 \) is the absolute rotational velocity of AS \( o_3 x_3 y_3 \) movement, \( (J_{E3} = const) \) is the moment of inertia of the load around the axis \( o_3 \).

**Force function**

The force function of the CE is defined as the sum of the elementary works done by the active moments of forces driving the corresponding payloads:

\[ U_{E} = \int dA_{E} = \int dA_{E1} + \int dA_{E2} + \int dA_{E3}, \]  

(6)

where \( dA_{Ei} \) is elementary work done by forces driving the payloads of the actuator \( Pr_i \).

Among active moments acting to the CE, we will highlight the torques of the electric actuators of the SCSoOC and the torques produced by gravitational forces acting to payloads. Forces and torques mechanism is shown in Fig. 4, where \( G_{Ei} \) is the vector of gravitational force acting in point \( CM_{Ei} \), \( M_i \) is the torque of the actuator \( Pr_i \).

![Figure 4. Forces in the subsystem](image)

Relations for works of the active moments are formulated as:

\[ dA_{E1} = \left( (M_1 + M_{G_{E1}}) \cdot d\varphi_1 \right) = \left( (M_1 + [G_{E1} \times R_{CM_{E1}}]) \cdot d\varphi_1 \right) \]  

(7)

\[ dA_{E2} = \left( (M_2 + M_{G_{E2}}) \cdot d\varphi_2 \right) = \left( (M_2 + [G_{E2} \times R_{CM_{E2}}]) \cdot d\varphi_2 \right) \]  

(8)
\[ dA_3 = ((M_3 + \overline{M}_\Xi) \cdot d\varphi_3) = ((M_3 + [G_\Xi \times R_{CM_\Xi}]) \cdot d\varphi_3) \tag{9} \]

**Lagrange equations of the second kind**

In this research, computation of the mass centers of the payloads of the SCSoOC actuators, the moments of inertia of the loads, kinetic energies, and force functions according to (2) – (9) is implemented with the Wolfram Mathematica notebook document. In the document, the Lagrangian, its derivatives with respect to generalized coordinates and velocities are also computed, and the formation of the Lagrange equations of the second kind for actuators \( P_{r_1}, P_{r_2}, P_{r_3} \) of the manipulator are formed. Further, solution of these equations relative to angular accelerations \( \ddot{\varphi}_i \) of the actuators will be called the dynamic equations of the CE motion, the relation \( |R| = R \) being correct for all vectors.

Since the CE has three degrees of freedom, three dynamic equations are defined for each of them. Dynamic equation for the first degree of freedom is described by:

\[
\varepsilon_1 = \{M_1 + g \sin \varphi_1 m_1 R_{c1} - (J_{\Xi 2} + J_{\Xi 3})\varepsilon_2 - J_{\Xi 3} \varepsilon_3 + \\
+ m_2 g [R_1 \sin \varphi_1 + 2g R_{c2} \sin(\varphi_1 + \varphi_2) + \\
+ R_{o2}(R_{CM_{\Xi 2}}(\omega^2 \sin \varphi_1 - \varepsilon_2 \cos \varphi_1) - \\
-(2\omega_1 + \omega_2) R_{CM_{\Xi 2}} \cos \varphi_1)] + \\
+ m_3 [g R_1 \sin \varphi_1 + 2g R_2 \sin(\varphi_1 + \varphi_2) + \\
+ 3g R_{c3} \sin(\varphi_1 + \varphi_2 + \varphi_3) - R_{CM_{\Xi 2}} R_{o2} \epsilon_2 \cos \varphi_1 - \\
- R_{o3}(R_{o3} \epsilon_2 + R_{CM_{\Xi 2}}(2\epsilon_2 + \epsilon_3) \cos(\varphi_1 + \varphi_3)) + \\
+ R_{CM_{\Xi 2}} R_{o2} \omega_1^2 \sin \varphi_1 + R_{CM_{\Xi 2}} R_{o3} \omega_1^2 \sin(\varphi_1 + \varphi_2) - \\
- R_{CM_{\Xi 3}} R_{o3}(\omega_2^2 + 2\omega_1 \omega_3 + \omega_2 \omega_3 + \omega_3^2) \sin(\varphi_1 + \varphi_3) - \\
- 2R_{o2} \omega_1 R_{CM_{\Xi 2}}(\omega_1 + \omega_2) \cos \varphi_1 - (2R_{o3}(\omega_1 + \omega_2) + \\
+ R_{CM_{\Xi 2}}(2(\omega_1 + \omega_2) + \omega_3) \cos(\varphi_1 + \varphi_3) R_{o3}])}/ \\
/J_{\Xi 1} + J_{\Xi 2} + J_{\Xi 3} + \\
+ (m_2 + m_3) R_{o2}(2R_{CM_{\Xi 2}} \cos \varphi_1 + R_{o2}) + \\
+ 2m_3 R_{CM_{\Xi 3}} R_{o3} \cos(\varphi_1 + \varphi_3) + m_3 R_{o3}^2), \tag{10} \]

where \( g \) is the gravitational acceleration; \( m_i \) is the mass of the element \( i \); \( R_{ci} \) is the distance between axis \( o_i \) and mass center of the element \( i \); \( R_i \) is the length of the element \( i \); \( R_{oi} \) is the distance between axes \( o_i \) and \( o_i \).

Dynamic equation for the second degree of freedom is described by:
\[
\varepsilon_2 = \{M_2 - (J_{\varepsilon 2} + f_{\Sigma 3})\varepsilon_1 - J_{\Sigma 3}\varepsilon_3 + m_2(2gR_{c2} \sin(\varphi_1 + \varphi_2) + \\
+ R_{CM_{\Sigma 2}} \omega_1^2 \sin \varphi_1 - (R_{CM_{\Sigma 2}} \varepsilon_1 + \omega_1 \dot{R}_{CM_{\Sigma 2}}) \cos \varphi_1) + \\
+ m_3 g(2R_2 \sin(\varphi_1 + \varphi_2) + 3R_{c3} \sin(\varphi_1 + \varphi_2 + \varphi_3)) + \\
+ R_{CM_{\Sigma 2}} R_{o2}(-\varepsilon_1 \cos \varphi_1 + \omega_1^2 \sin \varphi_1) - R_{o2} \omega_1 \dot{R}_{CM_{\Sigma 2}} \cos \varphi_1 + \\
+ R_{o3} \left(-\varepsilon_3 \varepsilon_1 + (\omega_1 + \omega_2) \frac{dR_{o3}}{d\varphi_2} (\omega_1 + \omega_2) - 2\dot{R}_{o3} \right) + \\
+ R_{CM_{\Sigma 3}} \varepsilon_3 \varepsilon_1 + (\omega_1 + \omega_2) (\frac{dR_{o3}}{d\varphi_2} (\omega_1 + \omega_2) - 2\dot{R}_{o3}) \right) \\
+ \frac{dR_{CM_{\Sigma 2}}}{d\varphi_3} \varepsilon_1 \omega_1 + \omega_2 + \omega_3 - (2(\omega_1 + \omega_2) \dot{R}_{o3}) \cos(\varphi_1 + \varphi_3) \} \right) / \\
/[J_{\varepsilon 2} + f_{\Sigma 3} + m_3 R_{o3}(2R_{CM_{\Sigma 3}} \cos(\varphi_1 + \varphi_3) + R_{o3})],
\]

where

\[
\frac{dR_{o3}}{d\varphi_2} = -\frac{R_1 R_2 \sin \varphi_2}{\sqrt{R_1^2 + R_2^2 + 2R_1 R_2 \cos \varphi_2}}
\]

Dynamic equation for the third degree of freedom is described by:

\[
\varepsilon_3 = \frac{1}{J_{\Sigma 3}} \left\{M_3 - J_{\Sigma 3} (\varepsilon_1 + \varepsilon_2) + \frac{dR_{CM_{\Sigma 2}}}{d\varphi_3} m_2 R_{o2} \omega_1(\omega_1 + \omega_2) \cos \varphi_1 + \\
+ m_3(3gR_{c3} \sin(\varphi_1 + \varphi_2 + \varphi_3) + \frac{dR_{CM_{\Sigma 2}}}{d\varphi_3} R_{o2} \omega_1(\omega_1 + \omega_2) \cos \varphi_1 + \\
+ R_{CM_{\Sigma 3}} (-R_{o3} \cos(\varphi_1 + \varphi_3) (\varepsilon_1 + \varepsilon_2) + \omega_2(\omega_1 + \omega_2) \sin(\varphi_1 + \varphi_3)) - \\
- (\omega_1 + \omega_2) \dot{R}_{o3} \cos(\varphi_1 + \varphi_3) \} \right),
\]

where

\[
\frac{dR_{CM_{\Sigma 2}}}{d\varphi_3} = -\frac{m_3 (m_3 R_2 + m_2 R_{c2}) R_{c3} \sin \varphi_3}{(m_2 + m_3)^2 R_{CM_{\Sigma 2}}}
\]

**Simulation model**

In this research, structure of the OC with the manipulator, which has bipolar SM-based electric actuators with absolute rotation angles feedback via tilt sensors, is considered. In flat task, position of the VC is definitely described by its distance to OO and angular foreshortening of its optical axis \( \varphi_d \) (Fig. 2). Required coordinates of the VC must be transformed to the control values of absolute angles \( \varphi_1^\Sigma, \varphi_2^\Sigma, \) and \( \varphi_3^\Sigma \) by the solution of inverse kinematics for three feedback actuators according to the CE gears diagram. Admitting \( R_d = \text{const} \), one can study the CE dynamics in feedback actuators association (FAA) during forced motion. Generalized structure of the SCSoOC can be represented as in Fig. 5, where \( SA_i \) are the stepper actuators; \( \theta_i \) are the errors of FAs; \( \theta_g \) is the guidance error. Blocks \( f_i \) are the dynamic equations obtained from (10), (11), and (13).
Simulation model of the bipolar SM-based actuator uses the SM mathematical model included the system of non-linear equations [9]. Practically, SM is operated with driver generated the control voltage for the exciting windings. Driver mathematical model supported microstep mode was designed for the imitation of the control voltages. The model is described by the following relations:

\[ U_A = A \sin \left( \frac{2\pi(n + D)}{4D} \right) \]

\[ U_B = A \sin \left( \frac{2\pi n}{4D} \right) \]

where \( U_A, U_B \) are the control voltages of the windings A and B, respectively; \( A \) is amplitude of the control voltage; \( D \) is the step divider value; \( n \) is the fixed-step control counter value corresponded to the current voltage:

\[ n_{t+1} = n_t + 1 \]

Switching frequency of the counter defines the control voltages frequency, i.e. step frequency of SM rotor, which corresponds to its rotational speed. Thus, SA includes SM, driver, and control counter.

Principle of a position feedback system design is based on decreasing the error signal up to zero with its stability. It is effective to use the error including information both about position coordinate and its derivative as an input signal of the counter in the system under consideration. The voltages of SA generated by driver must be fixed on the last received values in decreasing the error. It means that the counter must be fixed on some last value in this position as well. Thus, the counter counts to some maximum value proportional to the control angle \( \varphi^C \) (or maximum error) in decreasing the error up to zero. Therefore, it is effective to design the control counter in accordance with

\[ n = \left| K \int \theta \, dt \right| \]

where \( K \) [Hz/V] is the proportionality constant (further, gain) between error expressed in voltage and counter frequency.

Simulation model of the SCSoOC built in accordance with the structure in Fig. 5 and given data using MATLAB Simulink is shown in Fig. 6.
The solution of inverse kinematics is implemented in «Setter» block according to [8]; three control counters are generated in «Controller» block according to (18); the SA control voltages described by «Stepper Actuator» blocks are generated in «Driver» blocks according to (15) and (16); parameters of the dynamic equations are calculated in «Calculation Block». Dynamic equations (10) – (14) are considered in «Stepper Actuator» blocks in accordance with the SCSoOC structure (Fig. 5).

The characteristics of the American manipulator AR2 [11] are admitted as mass-dimensional parameters of the CE. The manipulator includes the following actuation motors:

- \( Pr_1 \) – NEMA 23HS22 – 2804SS – HG50 (Stepper Actuator 1);
- \( Pr_2 \) – NEMA 17HS15 – 1684S – HG50 (Stepper Actuator 2);
- \( Pr_3 \) – NEMA 17LS19 – 1684E – 200G (Stepper Actuator 3).

In simulation, distance between VC and OO is equal to 0.1 m.

Designer-defined gains \( y \), in fact, define the quality factor of each local FA and can be selected so that a subsystem will have required QI. One of the simulation tasks was the research of the influence of QI to transient response of the SCSoOC.

Responses of the SCSoOC to step input with amplitude \( \varphi_d = 5^\circ \) and different QI values are shown in Fig. 7.

The curves obtained show that speed of response of the SCSoOC increases with increasing of the gains. Significant increase of a gain can lead to the motor automatic braking phenomenon that can be seen from the transient response with gains equal to 140 Hz/V. This phenomenon appears when switching frequency of the control voltages is higher than motor speed capabilities defined by its load [4].
Rational (from out-of-non-synchronism-zone maximum speed of response perspective) gains values experimentally found are

\[
\begin{align*}
K_1 &= 120 \text{ Hz/V}, \\
K_2 &= 80 \text{ Hz/V}, \\
K_3 &= 115 \text{ Hz/V}. 
\end{align*}
\]  
(19)

Response to the input signal, which changes its value in the range $\phi_{d} = 5 \ldots 10^\circ$, i.e. initial error is equal to 5°, is considered for the research of dynamic accuracy of the SCSoOC forced motion. In that case, the behavior of the dynamic accuracy as a composition of QI, such as speed of response and dynamic accuracy in quasi-steady-state modes is researched. Simulation results are shown in Fig. 8.
With above-admitted rational gains values of the SCSoOC, speed of response is limited by the requirement of the missing to nonsynchronism zone, but after that both error and its derivative become less than the determined threshold (approximately during 0.2 s). Possibility is appeared to change gains values in a relay way to higher ones increasing speed of response and dynamic accuracy in the quasi-steady-state mode in this error zone. Using graded structure [12], we will consider the response to input signal providing gains values are corresponded to ones in (19) in the high deviation area ($\|\theta_g\| \geq 1^\circ$) and to experimentally defined increased values in the small deviation area ($\|\theta_g\| < 1^\circ$), i.e. approximately after 0.2 s):

$$
\begin{align*}
K_1 &= 690 \text{ Hz/V}, \\
K_2 &= 785 \text{ Hz/V}, \\
K_3 &= 700 \text{ Hz/V}.
\end{align*}
$$

Simulation results of the SCSoOC operation in gains switch mode are shown in Fig. 8 (curve 2).

Fig. 9 shows guidance errors of the SCSoOC defined as a difference between input and output signals:

$$
\theta_g = \varphi_d - \varphi_3^a
$$

Integral estimate of the dynamic error $\theta_g$ defined as an area under its curve is used for the quantitative estimation of the SCSoOC dynamic accuracy (Fig. 10).

$$
\bar{\Delta}_\theta = \int_0^T |\theta_g| \, dt
$$

Fig. 10 shows that relay switching of gains assists decreasing of dynamic error in the low error area. With speed of response of a SA limiting by threshold frequency of rotor steps, actuator operation area can be divided to more parts than two; in these parts, effective gains will be determined. Thus, SA will operate with maximum possible frequency on each part. It will allow to increase speed of response and dynamic accuracy of the SCSoOC.

Figure 9. Guidance errors
Results and conclusion

1. In this paper, research of the controlled elements of complex (in fact, multicoupling) system of the feedback actuators association is carried out. The research allowed to determine a description reduction methodology of the mechanical part of the system.

2. It is shown that stepper motors widely used in robotics can be constraint for speed of response of a system and thus decrease the overall dynamic accuracy in the mobile targets (observing object) tracking task.

3. Since gain selection criterion for each stepper-motor-based feedback actuator is a capability of achievement of the cutoff frequency of its operation, effective control option can be a partition of operation angular range of a stepper motor to the areas having their own gain. In high initial errors areas, maximum possible gain that will not be a reason of the motor automatic breaking phenomenon should be chosen. In low errors areas, the same gains influence to decreasing of both switching frequency of the control voltages and rotational speed of an actuator, and they should be increased in accordance with the requirements to given dynamic accuracy.

In conclusion, nonlinear control of a feedback actuators association is substantiated to decrease influence of the above-said constraints under defined conditions and thus to increase tracking dynamic accuracy of an observing object.

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