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Synthesis Azimuth Tracking Device

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ABSTRACT: Using analytical methods derived mathematical models of the dynamics of the elements and components of the servo system with the wave channels. At the same time, a model of the dynamics of slewing devices of tracking systems with wave channels. Presented procedure azimuth tracking system synthesis with perturbations of the moving object, reduced to the stochastic problem of control by expanding the state space. It is shown that synthesized azimuth tracker allows you to build a system of automatic control with zero steady-state error tracking the implementation of PI control law.

KEYWORDS: angle measuring device, azimuth tracking, moving objects, stochastic problem of control, static error of tracking, identification of the model parameters, operational forecasting, stochastic control problem.

I. INTRODUCTION

Methods of stochastic optimal control are becoming more common solutions for electronics applications. With the help of these methods are designed radio control systems [1] solved the problem of synthesis of optimal control algorithms by radio tracking systems for satellites [2], are being developed identification systems and tracking multiple targets [3], etc.

Stochastic control theory is based on a statistical approach to solving problems of identification, prediction, optimization and filtering. The lack of complete a priori information about the system of control caused by changes in external influences, as well as the characteristics of control objects in terms of their normal functioning, the impossibility of taking into account all the effects, and other factors make the actual constantly refine the operation and control of the laws of the object.

Great influence on the development of stochastic control theory had no use of digital computer. Filtering theory is developed, allowing to solve problems of pre-emption and the recurrent filtering methods with the wide involvement of digital computer [4, 5, 6]. The forecast given in the form of the output variable of the linear dynamical system (e.g. Kalman's filter) Based on the theory of filtration.

II. STATEMENT OF A PROBLEM

Consider the problem of azimuth tracking system for the synthesis of the subject [7]. Tracking tasks with perturbations reduce to stochastic control problems by increasing the state space. The predetermined portion consists of the antenna and the motor. At the time of antenna affects wind load - disturbance. The control problem is then exposed to the engine, wherein

$$\Theta(t) \cong \Theta^d(t), t \geq t_0,$$

where $\Theta(t)$ represents the angular position of the antenna, and $\Theta^d(t)$ - the angular position of the object. Assume that the angle $\Theta^d(t)$ is available for measurement by the DF apparatus. The desired portion of the system is described by the differential equation

$$J\ddot{\Theta}(t) + r\dot{\Theta}(t) = m(t) + m_B(t), \tag{1}$$

where J – moment of inertia of all rotating elements of construction, including an antenna; r – coefficient of viscous friction; $m(t)$ – torque developed by the engine; $m_B(t)$ – the time of the disturbance caused by the wind ("Environment"). It is assumed that the torque developed by the motor is proportional to the input voltage $u(t)$, i. e. $m(t) = ku(t)$.

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III. THE CONCEPT OF THE PROBLEM DECISION

Introducing the state variables $x_{11}(t) = \Theta(t)$ and $x_{12}(t) = \dot{\Theta}(t)$, write the differential equation (1) in the form

$$\dot{x}_1(t) = \begin{vmatrix} 0 & 1 \\ 0 & -a_{22} \end{vmatrix} x_1(t) + \begin{vmatrix} 0 \\ b_{22} \end{vmatrix} u(t) + \begin{vmatrix} 0 \\ c_{22} \end{vmatrix} v(t), \quad (2)$$

where

$$x_1(t) = [x_{11}(t) x_{12}(t)]^{\tau};\ a_{22} = r / J = 4{,}6c^{-1};$$
$$b_{22} = k / J = 0{,}787\, rad / B \cdot c^2;\ c_{22} = 1 / J = 0{,}1 кг^{-1} \cdot м^{-2}$$
$$J = 10\, кг \cdot м^2;\ m_B(t) = v(t).$$

Indignation $v(t)$ approximated by white noise with constant scalar intensity of V_1. Observable variable is the output of the potentiometer shaft antenna:

$$y_1(t) = x_{11}(t) + w_1(t), \quad (3)$$

where $w_1(t)$ - white noise with constant scalar intensity of W_1, $x_{11}(t) = \Theta(t)$ – the angular position of the antenna.
Model tracking is represented as a target exponentially correlated noise [7]:

$$\dot{x}_2(t) = -\frac{1}{\tau} x_2(t) + n(t), t \geq t_0, \quad (4)$$

where τ - the average time of the maneuver; $n(t)$ - scalar white noise with constant intensity N. Is assumed that the reference variable - the goal - is observed with additive noise

$$y_2(t) = x_2(t) + w_2(t), \quad (5)$$

where noise has a constant intensity of W_2 and are not correlated with the noise intensities of $n(t)$. $v(t)$ and $w_1(t)$ are equal

$$V_1 = 10 H^2 \cdot м^2 \cdot c;\ W_1 = 10^{-7} rad^2 \cdot c.$$

Optimum observer (estimator) is described by the equations

$$\dot{\hat{x}}_1(t) = \begin{vmatrix} 0 & 1 \\ 0 & -a_{22} \end{vmatrix} \hat{x}_1(t) + \begin{vmatrix} 0 \\ b_{22} \end{vmatrix} u(t) + \begin{vmatrix} K_1^1 \\ K_2^1 \end{vmatrix} [y_1(t) - |1 \quad 0| \hat{x}(t)], \quad (6)$$

$$\dot{\hat{x}}_2(t) = -\frac{1}{\tau} \hat{x}_2(t) + K_{21}[y_2(t) - \hat{x}_2(t)]. \quad (7)$$

Observer K coefficient matrix is calculated as follows. Riccaty equation for the variance given part has the form

$$\Delta\dot{X}^1(t) = \begin{vmatrix} 0 & 1 \\ 0 & -a_{22} \end{vmatrix} \Delta X^1(t) + \Delta X^1(t) \begin{vmatrix} 0 & 0 \\ 1 & -a_{22} \end{vmatrix} + \begin{vmatrix} 0 & 0 \\ 0 & C_{22}^2 V_1 \end{vmatrix} - \Delta X^1(t) \begin{vmatrix} 1 \\ 0 \end{vmatrix} \frac{1}{W_1} |1 \quad 0| \Delta X^1(t),$$

where

$$\Delta X^1 = \begin{vmatrix} \Delta X_{11}^1 & \Delta X_{12}^1 \\ \Delta X_{21}^1 & \Delta X_{22}^1 \end{vmatrix}.$$

Using the fact that $\Delta X_{12}^1(t) = \Delta X_{21}^1(t)$, we obtain the following scalar system of differential equations, written by members of the $\Delta X_{ij}^1(t),\ i, j = 1{,}2$, the matrix $\Delta X^1(t)$:

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$$\Delta\dot{X}_{11}^{1}(t) = 2\Delta X_{12}^{1}(t) - \frac{1}{W_1}\Delta X_{11}^{1}(t),$$

$$\Delta\dot{X}_{12}^{1}(t) = \Delta X_{12}^{1}(t) - a_{22}\Delta X^{1}(t) - \frac{1}{W_1}\Delta X_{11}^{1}(t)\Delta X_{12}^{1}(t),$$

$$\Delta\dot{X}_{22}^{1}(t) = -2a_{22}\Delta X_{22}^{1} + c_{22}V_1 - \frac{1}{W_1}\Delta X_{12}^{1}(t). \quad (8)$$

Steady solution of these equations in the $t \to \infty$ is given by

$$\overline{\Delta X^{1}} = W_1 \begin{vmatrix} -a_{22} + a_{22}\sqrt{a_{22}^2 + 2\beta} & a_{22}^2 + \beta - a_{22}\sqrt{a_{22}^2 + 2\beta} \\ a_{22}^2 + \beta - a_{22}\sqrt{a_{22}^2 + 2\beta} & -a_{22}^3 - 2a_{22}\beta + \left(a^{22} + \beta\right)\sqrt{a_{22}^2 + 2\beta} \end{vmatrix}, \quad (9)$$

where $\beta = c_{22}\sqrt{V_1 / W_1}$.

Then, from the $\tilde{K}(t) = \begin{vmatrix} K_1 \\ K_2 \end{vmatrix} = \Delta X(t)\tilde{D}^{\tau}W^{-1}$ shows that establish the optimal coefficient matrix has the form

$$\overline{K} = \begin{vmatrix} K_1^1 \\ K_2^1 \end{vmatrix} = \begin{vmatrix} -a_{22} + \sqrt{a_{22}^2 + 2\beta} \\ a_{22} + \beta - a_{22}\sqrt{a_{22}^2 + 2\beta} \end{vmatrix}. \quad (10)$$

When used in the numerical values of the established values of the matrices of variances and gains are, respectively,

$$\overline{\Delta X} = \begin{vmatrix} 0{,}04036\cdot 10^{-4} & 0{,}8143\cdot 10^{-4} \\ 0{,}8143\cdot 10^{-4} & 36{,}61\cdot 10^{-4} \end{vmatrix}, \quad (11)$$

$$\overline{K} = \begin{vmatrix} K_1^1 \\ K_2^1 \end{vmatrix} = \begin{vmatrix} 40{,}36 \\ 814{,}3 \end{vmatrix}. \quad (12)$$

Similarly, there is a gain evaluator behavior goal

$$K_1^2 = -\frac{1}{\tau} + \sqrt{\frac{1}{\tau^2} + \frac{N}{W_2}}. \quad (13)$$

The index «2» at K denotes affiliation rate to the observer object as opposed to a «1» which refers to the membership of K observers are part of the system.

Let us now consider the position of the control law. Target or the functional quality criterion expressed as

$$J = K\left[\int_{t_0}^{t_1} \left\{\left[x_1(t) - x_2(t)\right]^2 + pu^2(t)\right\} dt\right]. \quad (14)$$

The resulting steady control law described by the expression $D_{11} = 1/V(t_1 - t),\ E\left[w_{11}(t)\right] = 0$:

$$x^*(t) = -\tilde{G}_1\hat{x}_1(t) + \tilde{G}_2\hat{x}_2(t). \quad (15)$$

In steady-state gain control law coefficients are

$$\tilde{G}_1 = \left[G_1^1 G_2^1\right] = \left[\frac{1}{\sqrt{\rho}} \cdot \frac{1}{b_{22}}\left(-a_{22} + \sqrt{a_{22} + \frac{2b_{22}}{\sqrt{\rho}}}\right)\right], \quad (16)$$

$$\tilde{G}_2 = \frac{b_{22}/\rho}{\left(\frac{b_{22}}{\sqrt{\rho}} + \frac{1}{\tau^2} + \frac{1}{\tau}\left(a_{22}^2 + \frac{2b_{22}}{\sqrt{\rho}}\right)\right)^{1/2}}. \quad (17)$$

IV. REALIZATION OF THE CONCEPT

Figure 1 shows a control structure of the system, resulting in a sentence that is measured $y_2(t)$. Therefore, a feedback loop is independent of the properties of the reference variable – purpose. Synthesized system has a significant error in the steady state. This is because the exponentially correlated noise has a relatively high power at high frequencies, and because the weighting coefficient ρ tends to limit control action $u(t)$ small value by tracking accuracy.

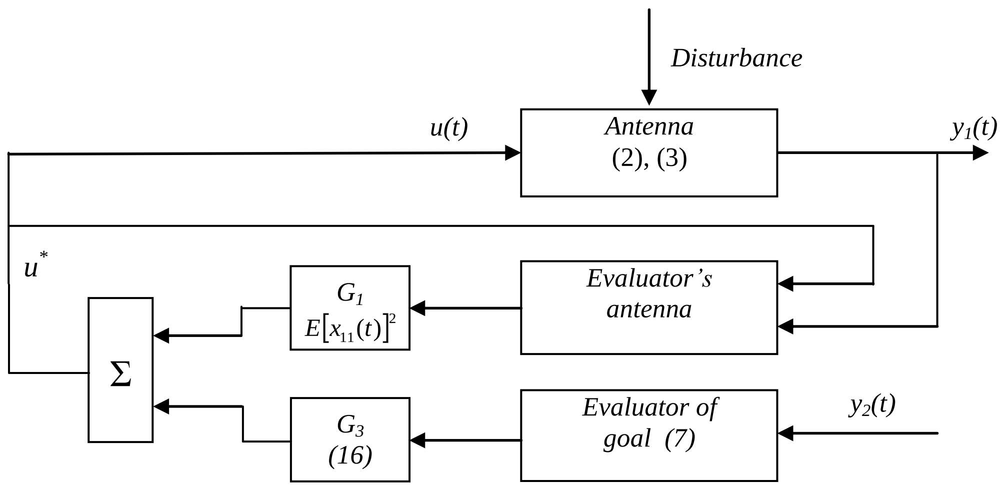

Fig. 1. Structure of the angle measuring device

To build a tracking system with zero steady tracking error, it is necessary to use proportional-integral control. In this case, the input of the system, apart from disturbing moment $v(t)$, receives a constant disturbance in the form of constant torque v_0. The equation of a predetermined portion (2) in this case is written as

$$\dot{x}_1(t) = \begin{vmatrix} 0 & 1 \\ 0 & -a_{22} \end{vmatrix} x_1(t) + \begin{vmatrix} 0 \\ b_{22} \end{vmatrix} u(t) + \begin{vmatrix} 0 \\ c_{22} \end{vmatrix} + v(t) + \begin{vmatrix} 0 \\ c_{22} \end{vmatrix} v_0 . \quad (18)$$

As before, the $v(t)$ - white noise with an intensity of V_1.
The optimal control law with zero steady-state error is described by

$$u^*(t) = -G\hat{x}(t) - \frac{c_{22}}{b_{22}}\hat{v}_0, \quad (19)$$

where $\hat{v}_0$ - v_0 score. The constant part of the perturbation can be represented as

$$\dot{x}_{20}(t) = n_0(t), \quad (20)$$

where white noise intensity is $n_0(t)$ V_0.

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The observed variable is described by equation (3). Establish the optimal observer described relations

$$\dot{\hat{x}}_1(t)=\begin{vmatrix}0 & 1\\ 0 & -a_{22}\end{vmatrix}\hat{x}_1(t)+\begin{vmatrix}0\\ b_{22}\end{vmatrix}u(t)+\begin{vmatrix}0\\ c_{22}\end{vmatrix}\hat{v}_0+\begin{vmatrix}\overline{K}_1\\ \overline{K}_2\end{vmatrix}\left[y(t)-\begin{bmatrix}1 & 0\end{bmatrix}\hat{x}_1(t)\right],$$

$$\dot{\hat{v}}_0(t)=\overline{K}_3\left|y(t)-\begin{bmatrix}1 & 0\end{bmatrix}\hat{x}_1(t)\right|, \qquad (21)$$

where the scalar koefficients K_1, K_2 and K_3 are determined by solving the Riccati equation for the observer (evaluator). For numerical values, and taken up

$$V_0 = 60H^2 \cdot \text{м}^2 \cdot c^{-1} \qquad (22)$$

These coefficients are $K_1 = 42.74,\ K_2 = 913.2,\ K_3 = 24495$.

The value (22) assumes that the mean square value of the increment v_0 of the period 1 second $\sqrt{60} \cong 7{,}75\, N \cdot m.$ This time is equivalent to the input voltage of the order of 1 V. As a result of the substitution of the control law (19) into equation evaluator can be seen that the system has a zero pole, i. e. it has an integrating effect.

V. CONCLUSION

The synthesis of goniometric tracking device, allowing to implement a system with zero steady-state error tracking, subject to a proportional-integral control law. Presented procedure azimuth tracking system synthesis with perturbations of the moving object, reduced to the stochastic problem of control by expanding the state space. It is shown that synthesized azimuth tracker allows you to build a system of automatic control with zero steady-state error tracking the implementation of PI control law.

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