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ALGORITHMS FOR FORMATION OF CONTROL EFFECTS IN CONDITIONS OF UNOBSERVABLE DISTURBANCES

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Abstract: this article develops an algorithm for synthesizing a complex-shaped command-tracking system based on modal considerations by compensating for interference signals when there is an effect of unknown unobservable disturbances on the control object. In this case, the control signal is selected in such a way that the output of the object must accurately and inertibly monitor each command signal. By predicting the future character of the object when the state of the system can be measured directly, we can ensure the observation of command signals using linear feedback to the state.Using Cauchy's formula, the matrix obtained by zeroing the co-head due to the galaions in the equation representing the exact output of the object is an poor-conditioned matrix. A modified Greville's constructive algorithm was used to determine these pseudo-inverse matrices. The structure of the resulting tracking system is built. Its main elements are the identifier of the command signal, the identifier of the interrupts and the state of the object. If the matrices in the identifiers are selected correctly, the system provides high-precision tracking of command signals even in the presence of any interference.

Keywords: non-measurable disturbances, indirect measurement, object condition estimation, combined control systems, and disturbance compensation.

I. Introduction

On the basis of modal considerations, we will consider the synthesis of systems that track commands of complex form in the presence of unknown and unmeasurable disturbances. We consider the unknown disturbance signal and the command signal as the output of some identifiable dynamical system with a known structure and an arbitrary initial state. Then we see a monitoring system for the ideal state, we assume that the ideal state is as follows: we can accurately measure the states of a fictitious (imaginary) dynamic system whose outputs coincide with the interference and command signals at any time, and then we construct the state identity of these dynamic systems, in which the ideal in state formulas, we replace the state with its value, these values are obtained at the output of the identifier, thereby forming a physically realized construction of the monitoring system.

Let some controlled and identifiable object be represented by the following equations:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) + \Gamma w(t), \\ y(t) = Cx(t), \end{cases} \quad (1)$$

Where $x(t) \in R^n$ – state vector, $u(t) \in R^m$ – vector of input effects, $y(t) \in R^p$ – vector of outputs, $w(t) \in R^r$ – vector of external disturbances, A, B, Γ, C – invariant matrices. If the outputs of objects are linearly independent, then $rank\, C = p$. The problem of controlling the object is as follows: the input $u(t)$ should be selected in such a way that the output of the object is equal to the previously given command signals of size $y(t)$ is equal to the previously given p - sized command signals $y_к(t)$. In addition, it should be possible to provide monitoring of command signals when the object is affected by unknown external interference $w(t)$.

Suppose that the command signal $y_к(t)$ is the output of an imaginary dynamic system

$$\begin{cases} \dot{r}(t) = Rr(t), \\ y_к(t) = Gr(t), \end{cases} \quad (2)$$

it is possible to measure directly where $y_к(t)$. R, G matrices are known, v - dimensional vector $r(t)$ refers to the state of the command process, which can change at any instant of time when the initial conditions change. The external disturbance $w(t)$ appears at the output of the imaginary dynamic system

$$\begin{cases} \dot{z}(t) = Dz(t), \\ w(t) = Hz(t), \end{cases} \quad (3)$$

where $w(t)$ is assumed to be impossible to measure directly, D, H matrices are given, the state of the p - dimensional $z(t)$ vector disturbance process, the initial conditions in (3) are unknown and may change at arbitrary time instants. Here, the functions $y_к(t)$ and $w(t)$ can be continuous due to changes in the initial conditions. (2) and (3) dynamic processes can be used to model many types of realistic interference and command signals.

Control $u(t)$ should be selected in such a way that the output $y(t)$ of the object follows each command signal $y_к(t)$ precisely and without inertia. $y_к(t)$, (2) can occur when there is any interference at the output of the system (3) that the system produces, $w(t)$ cannot be measured. In addition, control $u(t)$ must be physically implemented in the form of feedback on the output, i.e. $u(t) = (y(t), y_к(t))$.

We assume that the state of systems (1), (2), (3) can be directly measured, and we have all the information necessary to predict the future behavior of the object, and thereby define arbitrary good dynamics for tracking command signals using linear feedback on the state. We can ride. In this case, the control that solves the problem consists of two joiners

$$u(t) = u_п(t) + u_к(t), \quad (4)$$

Where $u_п(t)$ interrupt compensates for the effect of $w(t)$ on the object, and is a command signal when there is no interference $u_к(t)$ and in the absence of interference, the command signal $y_к(t)$ is observed.

II. Methods of evaluation of non-measurable disturbances

We insert object control (4) into equation (1) and using the Cauchy formula put $w(t) = Hz(t)$ in place and exit $y(t)$ the exact expression for can be written as [1].

$$y(t; x_0, t_0, z(t)) = Ce^{A(t-t_0)}x_0 + C\int_{t_0}^{t} e^{A(t-\tau)}Bu_к(\tau)d\tau + C\int_{t_0}^{t} e^{A(t-\tau)}[Bu_п(\tau) + \Gamma Hz(\tau)]d\tau$$

. (5)

So that the output $y(t)$ does not depend on the interference $w(t)$ the last addend in (5) must be zero.

In order to completely eliminate the effect of the disturbance $w(t)$ on the output $y(t)$ of object (1), we find a constant matrix Λ that satisfies the following condition

$$Ce^{A(t-\tau)}[B\Lambda + \Gamma H] = 0 \text{ all } t_0 \le \tau, t \le \infty. \quad (6)$$

In this case, the display of control will be $u_п(t) = \Lambda z(t)$. From (6), it seems to correspond to:

$$C[\hat{B}, A\hat{B}, A^2\hat{B}, ..., A^{n-1}\hat{B}] = 0, \quad \hat{B} = B\Lambda + FH, \quad (7)$$

which in turn gives rise to the following system of equations:

$$CA[B\Lambda + \Gamma H] = 0 \text{ when } s = 0,1,2,...,n-1.$$

If we consider the following matrix as well, its degree is equal to n because the pair of identifying matrices is $\{A, C\}$ condition (7) can be written as follows $rank[W^T, B, \Gamma H] = rank[W^T, B]$.

we use the following formula to calculate the matrix Λ

$$\Lambda = -(W^T B)^+ W^T \Gamma H + [I - (W^T B)^+ W^T B]Q_\Lambda,$$

here Q_Λ – arbitrary parametric matrix, I – unity matrix, W – n dimensional matrix $W=\left[C^T, A^T C^T \ldots\ldots\right]$.

In the case when the matrix F is not a full-rank matrix, then the problem under consideration is ill-posed. To give numerical stability to the procedure of pseudo-inversion of the F matrix, it is advisable to use the concepts of regular methods [2, 3, 5].

Let's consider some of the most constructive algorithms for determining pseudoinverse matrices [6, 7-14, 15].

Let us define a matrix of size $n\times m$, $F_m=(f_1, f_2, \ldots, f_m)$ the columns of which are the vectors f_j, $i=1,2,\ldots,m$. Using the obvious notation , this matrix can be represented as

$$F_m=(F_{m-1} \mid f_m),\; m=2,3,\ldots$$

Pseudo-inversions of the matrix D_1, are obviously carried out according to the formula

$$F_1^+ = f_1^T / f_1^T f_1.$$

To sequentially find the pseudo-inverse matrix D we will use the Greville method [16, 17]. From this we get

$$F_{m+1}^+ = \left(\frac{F_m^+\left[I - f_{m+1}k_{m+1}^T\right]}{k_{m+1}^T}\right),$$

where

$$k_{m+1} = \begin{cases} \dfrac{(I-F_mF_m^+)f_{m+1}}{\left\|(I-F_mF_m^+)f_{m+1}\right\|^2}, & if \quad (I-F_mF_m^+)f_{m+1}\neq 0, \\ \dfrac{(F_m^+)^T F_m^+ f_{m+1}}{1+\left\|F_m^+ f_{m+1}\right\|^2}, & in\, other\, cases \end{cases}$$

Accurate compensation of disturbances using control $u_п(t)=\Lambda z(t)$ is suitable even for continuous function when the state of the interrupting $z(t)$ process is known. This condition is appropriate only when it is possible to accurately measure the interference signal.

Now we will pay attention to the problem of assessing the state of systems (1), (2), (3). We believe that it is possible to actually measure only two quantities, the output of the object $y(t)$ and the command signal. When developing (constructing) the structure of the initial (zero) state adjuster, $x(t)$, $z(t)$, $r(t)$ the state vectors are obtained from the output of the identifiers, the ideal and only the measured quantities $y(t)$, $y_к(t)$ found using information about the optimal values , $\hat{x}(t)$, $\hat{z}(t)$, $\hat{r}(t)$ replacing (in the ideal case) the dynamic system as desired selection allows to build a monitoring system that can be put into practice For simplicity, we use state-estimating n-dimensional identifiers (Kalman filters). We write down the equations of the identifiers from which the estimate of the state of the object $\hat{x}(t)$ and the value of the state of interference is $\hat{z}(t)$ as follows:

$$\begin{bmatrix}\dot{\hat{x}}(t)\\ \dot{\hat{z}}(t)\end{bmatrix} = \begin{bmatrix}A+L_1C & \Gamma H\\ L_2C & D\end{bmatrix}\begin{bmatrix}\hat{x}(t)\\ \hat{z}(t)\end{bmatrix} - \begin{bmatrix}L_1\\ L_2\end{bmatrix}y(t) + \begin{bmatrix}B\\ 0\end{bmatrix}u(t), \qquad (8)$$

Where $y(t)$, $u(t)$ – are the actual output of the object and the actual input to (1), respectively. We assume L_1, L_2 matrices are chosen so that the value $[x(t), z(t)]$ and grade $[\hat{x}(t), \hat{z}(t)]$ let the difference between asymptotically approach zero: $[\varepsilon_x(t), \varepsilon_z(t)]^T = [x(t), z(t)]^T - [x(t), z(t)]^T \to 0$ if $t\to\infty$.

III.Condition assessment error.

The state estimation error equation has the following form:

$$\begin{bmatrix}\dot{\varepsilon}_x(t)\\ \dot{\varepsilon}_z(t)\end{bmatrix} = \begin{bmatrix}A+L_1C & \Gamma H\\ L_2C & D\end{bmatrix}\begin{bmatrix}\varepsilon_x(t)\\ \varepsilon_z(t)\end{bmatrix}. \qquad (9)$$

Since the pairs of matrices $\{A, C\}$ and $\{D, H\}$ are identifiers, it is possible to choose the corresponding matrices L_1, L_2 in such a way that the desired dynamics can be achieved, ensuring that the error of the identification state tends to zero. The following formulas can be used to construct the physically constructible state identifier $r(t)$ from the dimensions $y_к(t)$:

$$\dot{\hat{r}}(t) = [R+NG]\hat{r}(t) - Ny_к(t), \qquad (10)$$

where, R, G (2) is given in, N – is the matrix, which provides the rate of error tending to zero, which is chosen by the designer. The estimation error $\varepsilon_r(t) = r(t) - \hat{r}(t)$ satisfies the following equation:

$$\varepsilon_r(t) = [R + NG]\hat{\varepsilon}_r(t). \quad (11)$$

$t \to \infty$ da $\varepsilon_r(t) \to 0$ the matrix can always be chosen since the pair is identifiable if the dynamic of the pursuit is given.

Let's copy and write the equation of the observing system that can be physically implemented. To do this, we replace the $u_п(t) = \Lambda z(t)$, $u_к(t) = K_1 x(t) + K_2 r(t)$ in the $\{z(t),\ x(t),\ r(t)\}$ formulas with their values $\{\hat{z}(t),\ \hat{x}(t),\ \hat{r}(t)\}$ and create a physically implemented control with the following appearance:

$$\hat{u}(t) = u_п(t) + u_к(t) = \Lambda\hat{z}(t) + K_1\hat{x}(t) + K_2\hat{r}(t). \quad (12)$$

It can be shown that this control is actually a control that allows monitoring the signal appearing at the output of (2). In this case, we consider the dynamic behavior $\varepsilon_y(t) = y_к(t) - y(t)$ of the actual error of observation in the control (12) in the presence of arbitrary external disturbances produced by the system (3). For this, we put (12) into (1) and from the following expressions:

$$\hat{x}(t) = x(t) - \varepsilon_x(t),$$

$$\hat{z}(t) = z(t) - \varepsilon_z(t), \quad \hat{r}(t) = r(t) - \varepsilon_r(t),$$

using we get the following:

$$\dot{x}(t) = [A + BK_1]x(t) + [B\Lambda + \Gamma H]z(t) + BK_2 r(t) + B[\Lambda\varepsilon_x(t) - K_1\varepsilon_z(t) - K_2\varepsilon_r(t)]. \quad (13)$$

When a real object is affected by perturbations $w(t)$ and it is controlled in the form of feedback (12), the movement of the object is described by equation (13). Using the above, it is possible to consider the change of state variable $\varsigma(t)$ given by expression (10).

Using (13), the equation for $\varsigma(t)$ will have the following form:

$$\dot{\varsigma}(t) = [A + BK_1]\varsigma(t) - Vr(t) - \hat{B}z(t) + B[K_1\varepsilon_x(t) - K_2\varepsilon_r(t) - \Lambda\varepsilon_z(t)]. \quad (14)$$

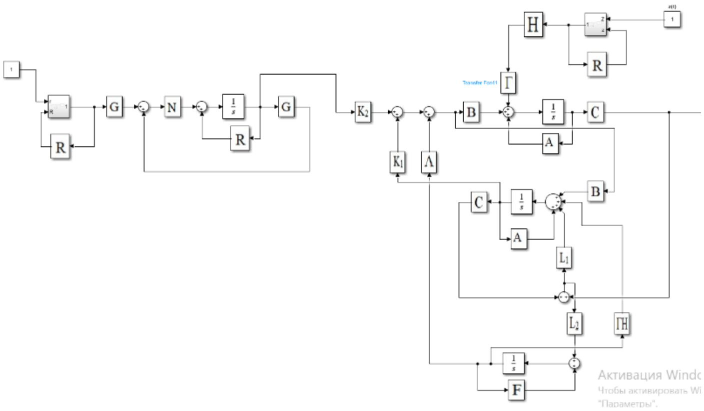
If the, K_1, K_2, N matrices in the identifiers are chosen correctly, the errors, $\varepsilon_x(t)$, $\varepsilon_z(t)$, $\varepsilon_r(t)$ tend to zero, and the variable $\varsigma(t)$ (2) jumps of the system between the initial conditions can be determined from the following formula:

$$\dot{\varsigma}(t) = [A + BK_1]\varsigma(t) - Vr(t) - \hat{B}z(t),$$

this is exactly consistent with equation (13).

IV. Conclusion

Therefore, the error asymptotically approaches zero, which means that the system provides high-precision tracking of command signals even in the presence of any disturbances. The structure of the resulting tracking system is shown in Fig. 1.



Its main elements are the identifier of the command signal, the identifier of the interrupts and the state of the object. The developed algorithms make it possible to synthesize a system that monitors complex commands based on modal considerations by compensating interference signals when there is an influence of unknown unobservable noises on the control object.

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