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ON DELAYED TECHNOLOGICAL OBJECTS AND THEIR CHARACTERISTICS

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Abstract: The article provides information about delayed objects, the causes of their delay, and methods of reducing delay time.

Keywords: Delay, mathematical model, signal, equation, time, delayed object, process, initial time.

Introduction. In the nature, there is a feature of technical devices, economic systems and many other processes that their future state depends on their previous state, that is, their history. It is known that in order to study any processes and phenomena it is necessary to build their mathematical model [1,3]. In this case the series variables of the research object are created with the participation of input variables in other words, controlling effects or controllers and output coordinates, controlled variables, intermediate variables [2,4]. The following expressions are used to create mathematical models: (y t) = {y (t),....(1)} - coordinates of the object; u(t) = {u(t),...,, (t)) - control keys; f(t)={f(t)......f(1)} perturbations, x(t)=x(t),...x(t)} interval variables. The concept of "delayed object" means that the research object has channels where signals are caught, that is, the signals of the object arrive at the control body with a certain time delay, time delay and

$$0=\tau_0<\tau_1<\ldots<\tau_l - \text{for x(t) from variables;}$$

$$0=\theta_0<\theta_1<\ldots<\theta_r - \text{- for variables (1).}$$

The mathematical model of the object whose signals are delayed expresses the analytical interrelationship between its essence and variables, and when using the accepted expressions, it has the following form:

$$F_0(y(t),x(t),u(t),f(t),\tau_1,\theta_1,\ldots,\tau_l,\theta_r)=0, \qquad (1)$$

when observing an object for continuous moments of time

$$F_0(y(kT),x(kT),u(kT),f(kT),\tau_1,\theta_1,\ldots,\tau_l,\theta_r)=0, \qquad k=0,1,\ldots, \qquad (2)$$

where $t=kT$ (T-discretion step), F_0- operator. The subject of our further research will be focused on dynamic objects, that is, events, phenomena, processes that change over time. For this reason, the expressions (1), (2) are in the form of differential, integral or difference equations. (1) represents continuous objects whose signals are delayed, and (2) represents discrete objects whose signals are delayed. Objects whose execution parameters are clear and fixed are called "deterministic" objects. Conversely, objects that are likely to occur are called "stochastic objects" [1-3].

Methods and results. Below, we specify the operator equations (1), (2) define the meaning of the variable x(t).

The concept of "state" is usually interpreted as the minimum information about the previous state of an object in order to judge its future state. In connection with the introduction of the concept of state, we describe the properties that the model of the delayed object should have [3,4]:

1. The output signal at a certain time depends strictly on the input signals and is determined by the current state.

2. The state at the next time instant t depends strictly on the input signal in the time interval $[t_0, t)$ (or $[t_0 - \theta_r, t)$interval $u(t, t_0 - \theta_r)$) and the state $x(t_0, t_0 - \tau_l)$ in the interval $[t_0 - \tau_l, t_0]$. We express these two conditions with two equations of state:

$$y(t) = g_1(x(t),\ u(t)),\ (3)$$

$$x(t) = g_2(x(t_0, t_0 - \tau_l),\ u(t, t_0 - \theta_r)),\ (4)$$

where g_1, and g_2 are functions with the same meaning.

The above considerations that apply directly to continuous objects can also be applied to discrete objects. We note that the minimum number of variables $x(kT)$ constitutes the state vector of the system. For this, it is necessary to find such as g_1 and g_2 such that the following equations are valid:

$$y(kT) = g_1(x(kT),\ u(kT)), \qquad (5)$$

$$x[(k+1)T] = g_2(x(kT), \ldots, x[(k-\tau_l)T],\ u(kT), \ldots, u[k-\theta_r)T]), \quad (6)$$

where $y(kT)$ is the output coordinate vector of the object (kT) at time instant $u(kT)$ is the vector of control effects at time instant (here and then, when looking at discrete objects, we assume that the delay time is a multiple of the discreteness period T, therefore, τ_i and θ_j are assumed to be given in relative units; $k_0 T$ - initial time instant.

The difference between the state equations written for continuous objects (3), (4) and those written for discrete objects (5), (6) is explained by the characteristics of discrete objects. The following two recurrent proportional systems of equations are essentially discrete analogues of the first two.

The state of a discrete object (with delayed and non-delayed signals) at an arbitrary instant of time is described by the finite quantity parameters, accordingly, the equations of state of discrete objects with delays do not differ from the equation of such objects whose signals are not delayed and are generally similar in form [3-5]. The state of the first at an arbitrary time is described by some function defined at intervals $[t_0 - \tau_l, t_0]$, $[t_0 - \theta_r, t_0]$ with the last amount of parameters (this is not the case with the second). This condition greatly complicates the issues of managing such objects.

In this article, stationary, linear dynamic models of delayed objects, the simplest of the series of delayed dynamic models, are considered. It is self-evident that this is a very approximate representation of real processes. However, when the dynamics of many processes are considered in the areas of slight deviations from the equilibrium regimes, linear dynamic systems describe the research object sufficiently. This serves as sufficient proof of the necessity and meaningfulness of their study.

The equation of state for objects whose coefficients are constant, linear, differential, difference equations, whose parameters do not change, that is, in simple terms, the equations of state for delay, continuous, stationary, linear objects have the following form.

$$\dot{x}(t) = \sum_{i=0}^{l} A_i x(t-\tau_i) + \sum_{i=0}^{r} B_i u(t-\theta_i), \quad (7)$$

$$x(t) = \varphi_x(t), \qquad t_0 - \tau_l \le t \le t_0, \quad (8)$$
$$u(t) = \varphi_u(t), \qquad t_0 - \theta_r \le t \le t_0,$$

where $\varphi_x(t)$, $\varphi_u(t)$ - is the initial function.

To be clear, this means output coordinates $y(t)$ and control effects $u(t)$ we assume that the learning vectors have the same dimension and are equal to n, that is, inputs objects with outputs were "n" viewed. The dimension of the state vector $x(t)$ is equal to $m \ge n$.

A, B, C, D are invariant matrices of corresponding size. Block diagrams corresponding to these equations are given in Fig. 1

It should be noted here that if $y(t)$ and $u(t)$ are real physical quantities and their choice strictly depends on the essence of the problem to be solved, then the intermediate parameters $x(t)$ the state of the object There is some freedom in choosing the vector.

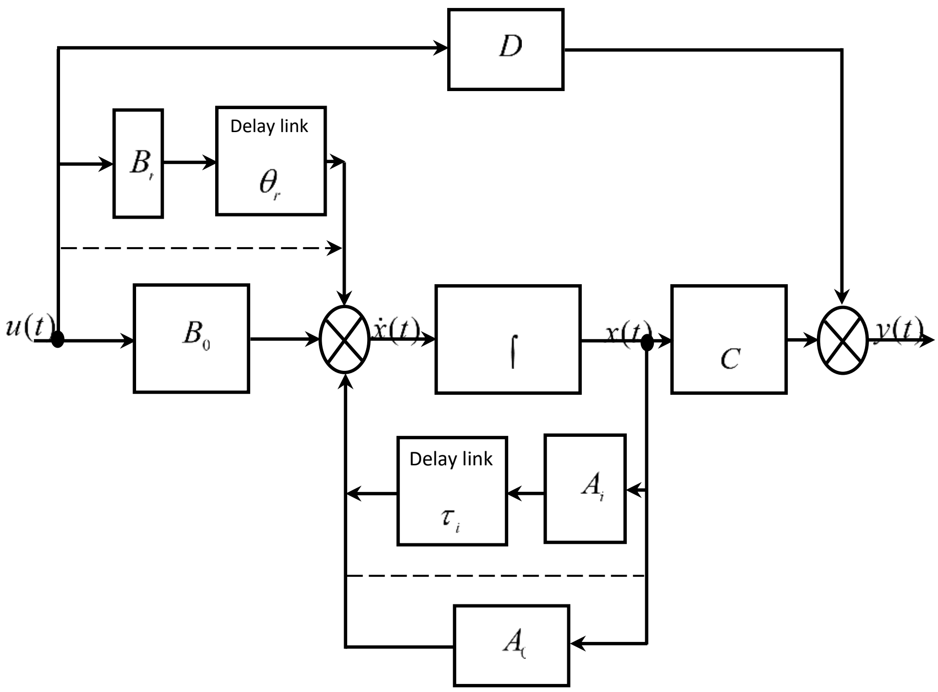

Figure 1. Block diagram of objects whose parameters are invariant and whose differences are differential, represented by straight-line equations.

Indeed, we consider some unbroken transformation [6]

$$x_1(t) = \Gamma x(t), \qquad |\Gamma| \neq 0. \tag{9}$$

the equations of state (7) and (8) with respect to $x_1(t)$ will have the following form:

$$y(t) = C_1 x_1(t) + Du(t), \tag{10}$$

$$\dot{x}(t) = \sum_{i=0}^{l} A_{1i} x_1(t-\tau_i) + \sum_{i=0}^{r} B_{1i} u(t-\theta_i), \tag{11}$$

It's here $\left.\begin{array}{l} A_{1i} = \Gamma A_i \Gamma^{-1}, \\ B_{1i} = \Gamma B_i, \quad C_1 = C\Gamma^{-1} \end{array}\right\}.$

The coefficients are expressed by constant, linear differential equations, for objects with constant parameters, that is, for delayed, discrete, stationary and linear objects, the state equations have the following form

$$y(kT) = Cx(kT) + Du(kT), \tag{13}$$

$$x[(k+1)T] = \sum_{i=0}^{l} A_i x[(k-\tau_i)T] + \sum_{i=0}^{r} B_i u[(k-\theta_i)T], \tag{14}$$

$$x(kT) = \varphi_x(kT), \qquad k_0 - \tau_l \leq k \leq k_0,$$

$$u(kT) = \varphi_u(kT), \qquad k_0 - \theta_r \leq k \leq k_0,$$

where $\varphi_x(kT)$, $\varphi_u(kT)$ – initial functions.

A general block diagram of the system similar to the one in Figure 1 (Figure 2)

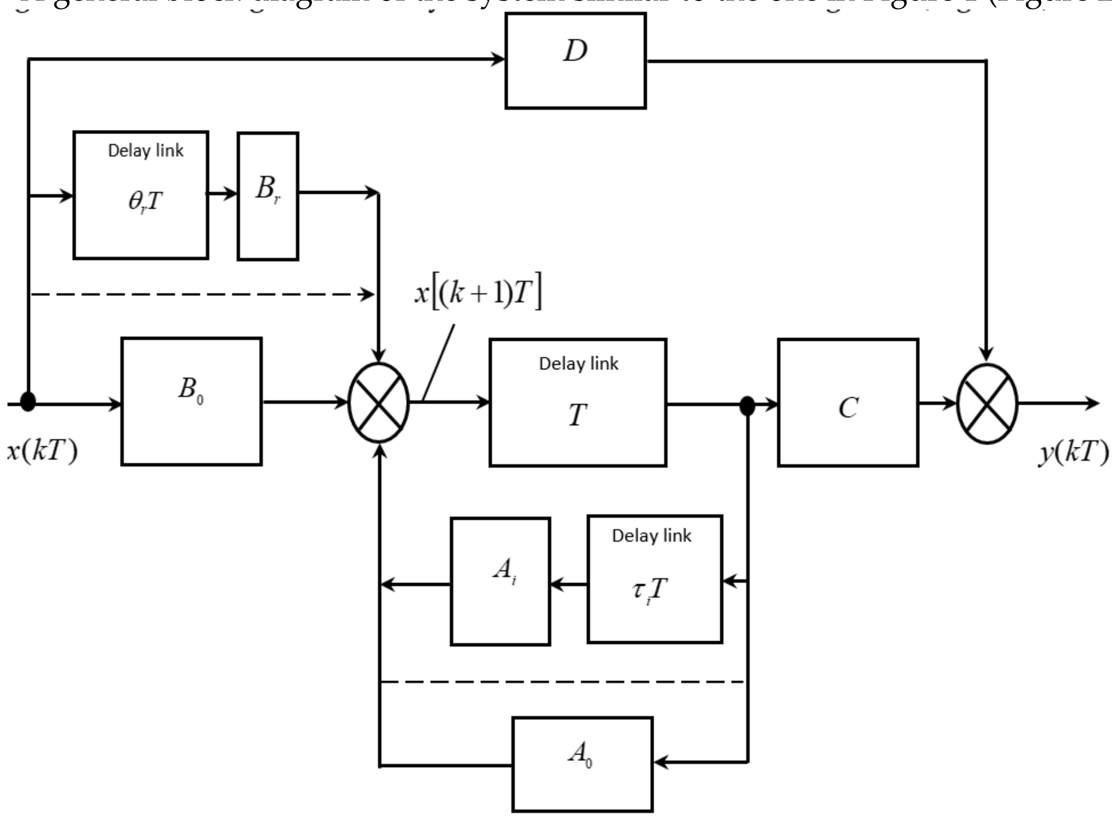

Figure 2. Block diagram of objects whose parameters are constant and whose differences are represented by straight-line equations

Like the state equations of continuous linear objects, expressions (13) and (14) also allow to change the state vector due to an intact linear transformation similar to (9), more precisely, (13) and (14) of the system with respect to the vector $y(kT)$ is invariant with respect to the linearly intact transform of the state vector of the object [3-6]. Generated it is not difficult to foresee that the matrices of the equivalent system can be found by means of (12). The given equations of state correspond to an isolated object, since the effect of the environment on the object in question is not taken into account.

It is not difficult to introduce a vector of disturbance effects represented by the state equations into the model of the object, since both u(t) and f(t) are essentially external effects (controlling and perturbing, respectively) and in this sense equal entitled. The equations of state of the object, taking into account the effects of turbulence factors, have the following form [3.6]:

$$\dot{x}(t)=\sum_{i=0}^{l}A_i x(t-\tau_i)+\sum_{i=0}^{r}B_i u(t-\theta_i)+B_f f(t), \tag{15}$$

$$x(t)=\varphi_x(t), \qquad t_0-\tau_l\le t\le t_0;$$

$$u(t)=\varphi_u(t), \qquad t_0-\theta_r\le t\le t_0;$$

$$y(t)=Cx(t),$$

where functions $\varphi_x(t)$ are related to $\varphi_y^{(i)}(t)$ $(i=0,1,\ldots)$ using expressions (17)

$$\left.\begin{aligned}
&x^q(t)=\sum_{i=0}^{l}L_0^i y(t-\tau)-\sum_{i=0}^{r}G_0^i u(t-0),\\
&x^{q-1}(t)=\sum_{i=0}^{l}(L_1^i+L_0^i p)y(t-\tau_i)-\sum_{i=0}^{r}(G_1^i+G_0^i p)u(t-\theta_i)-R_1 f(t),\\
&x^{q-2}(t)=\sum_{i=0}^{l}(L_2^i+L_1^i p+L_0^i p^2)y(t-\tau_i)-\sum_{i=0}^{r}(G_2^i+G_1^i p+G_0^i+p^2)u(t-\theta_i)-(R_2+R_1 p)f(t),\\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\
&x^1(t)=\sum_{i=0}^{l}(L_{q-1}^i+L_{q-2}^i p+\ldots+L_0^i p^{q-1})y(t-\tau_i)-\sum_{i=0}^{r}(G_{q-1}^i+G_{q-2}^i p+\ldots+G_0^i p^{q-1})u(t-\theta_i)\\
&-(R_{q-1}+R_{q-2}p+\ldots+R_1 p^{q-2})f(t).
\end{aligned}\right\}$$

It should be noted that while considering the control issues, we study the system of equations with the delay argument in the interval $[t_0,t]$. Here the initial conditions for $x(t)$, $u(t)$ $[t_0-\tau_l,t_0]$, $[t_0-\theta_r,t_0]$ we consider the interval and assume that $u(t)$ $f(t)$ and the initial conditions make the solution continuous [6-8].

The following state equations in the form (15), (16) correspond to most types of real objects with delays. Hereafter, we sometimes use a more general expression than (16), that is, we assume that there is a direct connection between the output and input signals:

$$y(t)=Cx(t)+Du(t),$$

therefore, taking into account the effects of disturbances, we consider the following model of objects with delays in expressions (7), (8):

$$\left.\begin{aligned} y(t) &= Cx(t) + Du(t), \\ \dot{x}(t) &= \sum_{i=0}^{i} A_i x(t-\tau) + \sum_{i=0}^{r} B_i u(t-\theta_i) + B_f f(t), \end{aligned}\right\} \quad (19)$$

where B_f is an invariant matrix of appropriate size.

$$\left.\begin{aligned} A_i &= \begin{Vmatrix} 0 & 0 & 0 & \dots & 0 & -L_q^i (L_0^0)^{-1} \\ E\delta_{i0} & 0 & 0 & \dots & 0 & -L_{q-1}^i (L_0^0)^{-1} \\ 0 & E\delta_{i0} & 0 & \dots & 0 & -L_{q-2}^i (L_0^0)^{-1} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \dots & E\delta_{i0} & -L_1^i (L_0^0)^{-1} \end{Vmatrix}, \\ B_i &= \begin{Vmatrix} G_q^i \\ G_{q-1}^i \\ \dots \\ G_1^i \end{Vmatrix}, \quad B_f = \begin{Vmatrix} R_q \\ R_{q-1} \\ \dots \\ R_1 \end{Vmatrix}, \\ C &= \begin{Vmatrix} 0 & 0 & \dots & (L_0^0)^{-1} \end{Vmatrix}, \end{aligned}\right\}$$

δ_{i0} - The epitome of a chronicler

The objects whose delay is only in the control signals constitute an important class ((8), (14) in equations $A_i = 0, \quad i \neq 0$). These are called objects with control delay. This the common "subclass" of objects with pure latency belongs to the class ((8) ($A_i = 0, \quad i \neq 0, \quad B_0 = 0$) in equations (14)). Examples of such objects are models of many production systems, in particular, flow production models [9-11]. models of stock management problems [12-13], models of human behavior and many technical objects [14] . Only the objects whose coordinates have a delay form a separate class ((8), in equations (14) $B_i = 0, \quad i \neq 0$). These are called delayed coordinate objects. This class describes recycling processes, such as processes in chemical reactors of grinding aggregates.

Conclusion. Due to the fact that the mathematical models of linear dynamic objects with delay are expressed in different forms, there are also different approaches to finding a solution to the problems of synthesizing optimal closed-loop control systems. For these reasons, this article focuses on expressions of type (1), (2) related to objects of the said class.

Particular attention is paid to the approximation of the dynamic properties of continuous objects with a delay by special linear differential equations.

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