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Research Article

ON THE METHOD OF CONTROLLING OBJECTS WHOSE MOTION IS DESCRIBED BY A SYSTEM OF LINEAR DIFFERENTIAL-DIFFERENCE EQUATIONS

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ABSTRACT

This article explores the methods of controlling objects whose motion is described by a system of linear differential-difference equations. It provides an analysis that serves as a basis for developing an approach to eliminate existing shortcomings.

KEYWORDS

Control function parameters, optimal solution, kinematic chain, system of differential-difference equations.

INTRODUCTION

The shortcomings of controllability in linear stationary systems are described in [1], and these issues are also relevant for systems of differential-difference equations. The primary criterion for checking the full controllability of such systems is Kalman's criterion, which applies universally to controllable systems.

The general form of a system of linear differential-difference equations is as follows::

$$\begin{cases} \dot{x}(t) = Ax(t-h) + Bu(t) \\ y(t) = Hx(t) \end{cases} \quad (1)$$

where: $x = x(t) - n -$ a vector representing the state of the system at time t;

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A – constant matrices of specific dimensions; $(n\times n)-$ ўлчовли ўзгармас матрица;

$B-(n\times m)-$ A constant matrix with non-zero elements;;

$h-$ an infinitesimally small quantity;;

$u(t)-(1\times m)-$ a control function vector; $h>0,\ t_0\le t\le T$;

$y(t)-n-$ a vector of specific dimensions depending on the state vector $-(1\times n)$;

$H-(r\times n)-$ A constant matrix of specified dimensions.

The first equation in (1) represents the differential-difference equation, while the second equation describes the phase state of the first one.

Main Section. Objects whose motion is described by a system of differential-difference equations, particularly for industrial robots, have the following advantages and disadvantages for the system in (1):

1. **Motion system:** Deterministic.
2. **Control system:** Deterministic.
3. **Form of the motion model:** Linear differential-difference equation- $\dot{x}(t)=Ax(t-h)+Bu(t)$.
4. **Advantage of the model:** The form of the model is simple for systematic analysis and convenient for verifying full controllability using Kalman's criterion.
5. **Disadvantage of the model:**

It is known that if $rank[B, AB, A^2B,\dots, A^{n-1}B]=n$ the system (1) is fully controllable according to Kalman's criterion. In the system of equations (1), the matrix B has dimensions of $-(n\times m)$, particularly for the motion of industrial robots, $m=n$.

Thus, the matrix, $B\ (n\times n)-$ is extended to the required dimensions. The dimension of the controllable subspace of the system (1) becomes equal to n n. As a result, the obtained system satisfies the property of full controllability in R^n-dimensional space but does not satisfy the property of observability. To ensure the property of full controllability, the system (1) is considered as two autonomous systems as follows [2]:

$$\begin{cases} \dot{x}_1^1(t)=A_{11}x_1^1(t-h)+B_{11}u_1(t) \\ \dot{x}_2^1(t)=A_{22}x_2^1(t-h) \\ y(t)=H_1x_1^1(t)+H_2x_2^1(t) \end{cases} \qquad (2)$$

The second part of the system (2) is discarded because it does not satisfy the property of observability. In practice, particularly in the complex phase motion of industrial robots, the second part of system (2) complements the properties of the first part [1].

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From this, it becomes evident that additional scientific research is required to develop control methods for linear differential-difference systems.

For linear differential-difference systems, the following problem is posed:

Is it possible to ensure full controllability of the system (1) by optimizing the number of parameters of the control function during its management?

The problem was posed in a similar form for autonomous control systems in [1]. However, although the system was given in an autonomous linear form, the problem concerning the differential-difference nature of the system was not resolved., pecifically, in mathematical terms $f : R^1 \times R^n \times R^k \to R^n - (f -$ continuous function) does there exist a control function $v(t) \subset R^k \subset R^n - ?$

The problem condition is defined as follows:

The system is in the form of a linear differential-difference equation.

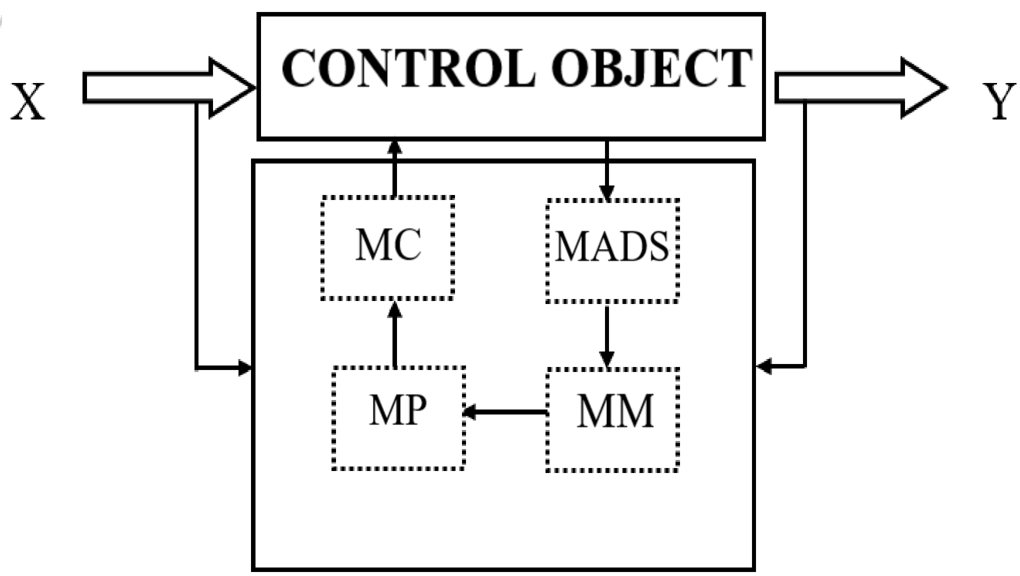
The system is finite-dimensional.

For robotic systems, the problem is posed as follows:

It is known that the stages of industrial robot motion can be divided into three phases: strategic, tactical, and execution. In the strategic phase, design issues are addressed; in the tactical phase, modeling and planning are carried out; and in the execution phase, control issues are solved. This is schematically represented as shown in Figure 1:

In this case, MADS–the methods of automated design systems; MM- methods of modeling; MP- Methods of planning.; MC- Methods of control.

Figure 1. Control diagram of an industrial robot.



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CONCLUSION

The issues of designing, modeling, and controlling industrial robot motion have been thoroughly studied, investigated, and the necessary results have been obtained. An analysis of the literature on the research topic revealed the following shortcomings and gaps related to industrial robot motion modeling and control:

It is known that the dynamic motion of an industrial robot is expressed using Lagrange's second law, Newton-Euler, D'Alembert, Gauss, Appel, and Kane equations, and there are several methods for solving these equations [3, 4]. When solving these equations, the number of equations increases twofold in relation to the number of unknowns [4]. This indicates that in the case of the robot's complex phase motion, the optimal trajectory is not unique. The decision-maker is unable to reach a consensus in choosing the appropriate trajectory. As a result, the process stops due to the collision of the industrial robot with objects in the external environment [5]. The SR (robot arm) changes the structure of the working hand. Such cases lead to excessive dependencies in the kinematic chain of the industrial robot, which requires the acceptance of alternative solutions and further research [1].

2. For the optimal control of an industrial robot, errors in calculating the coefficients of the system of equations representing its motion in trapezoidal form, as well as obstacles in communication channels, can lead to delays in the movement of the robot's links and an increase in the overall time required for technological operations. Furthermore, this can cause a decrease in the stability of the robot's motion and deteriorate its performance.

From these shortcomings in the mathematical models of the industrial robot's motion and their solving methods, it is evident that the correct specification of robot motion and the execution of complex phase operations, based on technical and design characteristics, require the development of an optimal solution. Effective use of control function parameters in selecting the appropriate solution enhances the robot's operational efficiency. This, in turn, highlights the necessity to improve the methods of modeling and controlling industrial robot motion.

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