MATHEMATICAL MODELLING OF AUTOMATION OBJECTS THROUGH PARAMETRIC IDENTIFICATION AND DIGITAL TWINS

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Annotation**:** The paper considers mathematical modelling of automation objects using linear differential equations, parametric identification, and digital twins. The dynamics of the object model is described through the relationship between the controlled parameter x(t) and the control parameter u(t). Accurate determination of coefficients based on experimental data allows us to adequately reproduce the dynamics of the system and promptly respond to changing operating conditions. Continuous monitoring, forecasting, and optimization of operating modes is facilitated by the integration of digital twins, which are constantly updated using data from sensors and SCADA systems. For high-tech and critical industries of Industry 4.0, it is very important that the synergy of these approaches increases the efficiency, reliability, and safety of automation object management.

Key words: smart cities, automation objects, modelling, parametric identification, digital twins.

RELEVANCE OF RESEARCES. With the development of high-tech industries and the introduction of automation in the context of Industry 4.0, mathematical modelling of automation objects is gaining considerable popularity. These approaches are used in manufacturing, energy, transport, and monitoring of complex systems. The key aspect is the accurate reproduction of the object's dynamics and effective process control using parametric identification and digital twins. The first allows you to determine unknown model coefficients based on experimental data, and the second allows you to quickly monitor and predict the state of the object in real time. Taking into account different operational requirements, it is necessary to adapt and improve these methods to increase the accuracy, speed of modelling, and productivity of automation systems.

MATERIALS AND RESULTS OF RESEARCHES. The principal property inherent for automation objects is that some state of this automation object must be provided by means related suitable influences on this automated object. The parameter envisaged to define the state of the automation object is the controlled parameter, but the parameter defining the influences on the automation object is the controlling parameter. Thus, if the considered phenomenon represents exactly the automation object, then the controlled and controlling parameters must be introduced necessarily. The processes inherent for automation objects can have different nature, so to represent generally mathematical models of automation objects, it is necessary to use correspondent abstract mathematical notions. Taking into account the necessarily introduced controlled and controlling parameters, the mathematical model of the automation object can be represented generally by the following mapping:

$$u(t) \to x(t), \tag{1}$$

where t is the time defining changes of the state of the automation object during the time; $x = x(t)$ is the controlled parameter, and $u = u(t)$ is the controlling parameter of the automation object.

In the general case, the mapping (1) is given by means the linear ordinary differential equation:

$$a_n \frac{d^n x}{dt^n} + \ldots + a_1 \frac{dx}{dt} + a_0 x = u(t), \tag{2}$$

where $n, a_n, \ldots, a_1, a_0$ are numbers, whose are the parameters of the mathematical model.

The construction of the differential equation (2) is reduced to determining its order and parameters. The order n is determined by expert estimates based on the analysis of processes inherent for the automation object. It is proposed to determine the parameters of the mathematical model (2) by means the parametric identification:

$$u(t), x(t) \rightarrow a_n, \ldots, a_1, a_0, \tag{3}$$

where $u(t)$ and the corresponding $x(t)$ are traditionally taken from experiments (tests).

The idea is to form the data about $u(t)$ and the corresponding $x(t)$ parameters by using digital twins of the processes inherent in the automation object. The parametric identification is a set of methods that allow finding unknown parameters of a mathematical model based on measurement data of input and output signals of the system. The combination of classical least squares methods with computational intelligence algorithms allows to significantly increase the accuracy of determining parameters in real production conditions. The study emphasizes the importance of high-performance data collection and processing for identifying models of complex objects, since this directly affects the speed and accuracy of setting up the control system. Thanks to effective identification, the resulting model makes it possible to assess the change in the state of the object in dynamics; predict possible deviations or critical operating modes; promptly adjust control actions.

Digital twins create a virtual replica of a physical product, process or system. The replica can for example predict when a machine will fail, based on data analysis, which allows to increase productivity through predictive maintenance [1]. An important feature of the software analogue of a physical device, which models the internal processes, technical characteristics and behavior of a real object under the influence of obstacles and the external environment, is the assignment of input influences. A virtual model of a physical object, which is updated in real time based on data from sensors, SCADA systems and other sources, allows you to constantly monitor the condition of the object; optimize the maintenance plan; test various control scenarios without risk to the equipment; increase the accuracy of identification and provide preventive diagnostics. The study emphasizes the importance of integrating digital twins with parametric identification methods: when the object model is promptly adjusted as a result of data updates, this provides increased accuracy and flexibility of the control system. As a result, the "identified" model can serve as the core of a digital twin. This allows for the most accurate reproduction of the dynamics of the automation object and calculations of various operating modes without stopping real production.

CONCLUSIONS. Thus, mathematical modelling of automation objects through linear differential equations, parametric identification and digital twins is a key direction in the development of modern control technologies. The linear model adequately reproduces the dynamics of the automation object provided that the coefficients are accurately determined, which are adjusted using parametric identification based on experimental data. The integration of digital twins allows you to continuously update model parameters, predict and optimize operating modes in real time, which increases the reliability and speed of decision-making. This synergistic approach is especially relevant for high-tech industries in the context of Industry 4.0, and further research should focus on improving identification algorithms and expanding the functionality of digital twins for complex multi-factor systems.

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