Applied problems of information systems operation

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DECENTRALIZED INFORMATION SYSTEMS IN INTELLIGENT MANUFACTURING MANAGEMENT TASKS

Abstract. The **object of research**: the process of distributed management of production processes in intelligent manufacturing. The **subject of the study**: a model of a decentralized system of technological process management in the production area of a modern plant, taking into account the concept of Industry 4.0. The **purpose of the research**: improvement of the management methods of intelligent production processes to ensure the execution of the technological process resistant to external influences and to ensure the specified indicators of product quality. The following **research methods are used**: methods of analysis and synthesis of decentralized production systems, modeling methods and theories of automatic control, mathematical apparatus of matrix theory, methods of describing linear dynamic systems. **Obtained results and conclusions**. In this work, the simulation of the decentralized information system for controlling the production site of intelligent manufacturing using manipulator robots with an angular coordinate system based on servo drives, which act as stepper motors, is carried out. To ensure the stability of the distributed system, parallel decentralization of the control process is proposed and the architecture of the organization of interaction between the components of the cyber-physical system based on it is given. A feature of the proposed model is the consideration of sensors as part of the feedback of the decentralized control system. The result of the simulation is the stability of the decentralized cyber-physical system to external influences for the selected transient characteristics.

Keywords: Industry 4.0; IoT; IIoT; Intelligent Manufacturing; Cyber-physical Systems; Robot; Manipulator; Decentralized Control System.

Introduction

The implementation of the Industry 4.0 concept in the manufacturing sector has led to the emergence of a new class of automated production, namely intelligent production complexes (smart manufacturing).

Managing intelligent manufacturing is a complex process that combines diverse equipment, sensors, actuators, human and material resources, planning tools, logistics, etc., into a single cohesive mechanism. Information flows into the management system from various sources generated by individual devices at each stage of the technological process.

The relevance of the research lies in the need to improve management processes in modern intelligent manufacturing systems to ensure compliance with the concept of Industry 4.0 and even 5.0. Application of the model of decentralized management of cyber-physical systems solves the problem of ensuring the stability of production processes to external influences and improves the quality of products. The transition to decentralized management allows for constant monitoring and control of the production process in real time, which is critically important in modern conditions of dynamic production and changing market needs.

This approach makes it possible to increase the efficiency of production processes and ensure the flexibility of the management system for quick response to changes in the production environment and consumer requirements.

The object of research is the process of distributed management of production processes in intelligent manufacturing. The subject of the study is a model of a decentralized system for managing technological processes in the production area of a modern plant, taking into account the concept of Industry 4.0.

The purpose of the research: improvement of the management methods of intelligent production processes to ensure the execution of the technological process resistant to external influences and to ensure the specified indicators of product quality.

Intelligent manufacturing [1–5] is a way of organizing the production of intelligent services or intelligent products, based on the search, accumulation, growth, and transformation of knowledge used as the foundation for production organization. The intelligent manufacturing management system allows knowledge to be collected in a single center (cloud storage) separate from their carriers (using blockchain technology) and transmitted to a worker who interprets them to create a product to meet customer needs.

The main task of intelligent manufacturing management is to organize the resilient execution of the technological process to ensure the specified quality indicators of the product [1].

Research is aimed at solving the problem of organizing process management at intelligent manufacturing. Based on the results of similar works in this field, the use of parallel decentralization of the control process is proposed, the architecture of the organization of interaction between the components of the cyber-physical system based on it is given, and mathematical modeling of the system based on distributed controllers is carried out.

Analysis of the problem of creating intellectual production

In work [6], the problem of the gradual implementation of the fourth technological revolution and industrial transformation, which is carried out thanks to information and communication technologies, is considered. Technologies that change existing manufacturing processes are considered: robotics, digital manufacturing, reinforcement learning, and brain computing. The authors of the article propose the latest intelligent technological production system, which is autonomous and controlled. This structure integrates the levels of corporate equipment, control and management, which greatly expands the capabilities of the intelligent factory and promotes the development of high-level production.

Another work is the analysis of the application of parallel additive manufacturing technology [7]. In this work, a concept is proposed that combines decentralized intelligent production with additive manufacturing. The problem of the lack of feedback in online mode for the production system is considered, which affects its reliability and stability. The use of prototyping and 3D printing tools provides a basis for transforming existing production and transitioning to the Industry 4.0 concept. Therefore, it is proposed to use integrated systems with artificial intelligence that employ a methodology for conducting virtual experiments with simultaneous parallel execution of the 3D printing process to make 3D printers intelligent.

The next task for intelligent manufacturing is resource and production facility management. To intellectualize this process, it is necessary to apply state-of-the-art information technologies and identification principles [8, 9]. This work demonstrates the structure of a production area management system. The components of intelligent production include CNC machines, autonomous carts for moving products and parts for their production, and monitoring tools for measuring technological process parameters. All components of automated production are interconnected in a unified computational network, enabling the management of goods and raw material logistics. Control over the use of material resources and intelligent identification is achieved using radio frequency identification (RFID) devices. The authors of the paper give suggestions on the organization of the software structure of the decentralized management of the production process at the intelligent factory.

In the work [10], the issue of protecting cyber-physical systems (CPS) from cyber attackers is examined. Considering that cyber-physical systems rely on computational networks for managing physical processes and providing critical services, attacks on these systems can have dangerous real-world consequences. This work provides indicators for quantitatively assessing the level of cyber resilience of CPS based on criteria such as structural integrity, stability, and performance during attacks. Using the proposed mathematical model based on drive saturation, these indicators allow for a quantitative evaluation of the ability of CPS to recover their functionality.

The architecture of intelligent manufacturing

Intelligent manufacturing systems consist of several subsystems that provide technological, dispatching, transportation, manipulation, and other operations. These subsystems should be equipped with auxiliary tools that provide them with a certain level of intelligence. Thus, the transition to intelligent manufacturing can be considered as an advanced phase of flexible production systems. The components of intelligent manufacturing systems are shown in Fig. 1.

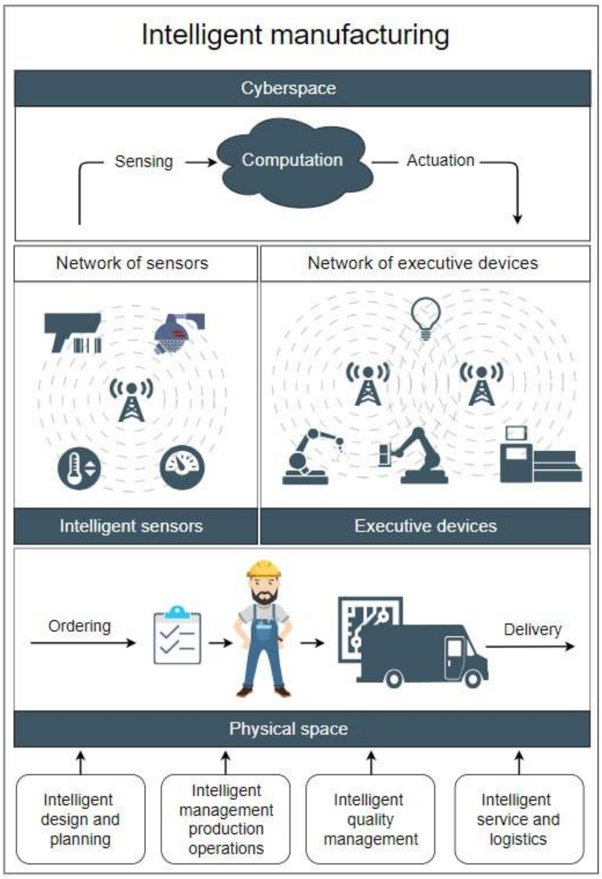


Fig. 1. The components of intelligent manufacturing systems

As can be seen from the provided illustration, the components of intelligent manufacturing systems include: intelligent design, intelligent quality management, intelligent management of production operations, intelligent personnel management, smart planning, and intelligent maintenance [11, 12].

In intelligent manufacturing, one can distinguish between the physical space and cyberspace. Production resources related to the physical space include universal machines and auxiliary equipment, industrial robots, manipulators, autonomous vehicles with intelligent control (AGV), as well as production personnel [13-17].

Data necessary for the execution of the technological process are collected from intelligent sensors, RFID devices, computer vision systems, and measuring devices. These sensors are the source of information for the cloud environment, which accumulates data, performs big data processing, carries out computations, and generates recommendations for the operation of executive devices. In the intelligent factory, these resources constitute cyberspace.

The integration of physical space and cyberspace is achieved through distributed, high-speed information networks [18, 19]. The foundation of such networks is formed by the information technologies of the industrial internet of things (IIoT) [20, 21].

This concept of building intelligent manufacturing with decentralized control of production processes has been named cyber-physical systems. Based on input information from a network of sensors, CPS performs calculations and influences physical devices to achieve high quality, flexibility in production, and reduction of raw material costs. Thus, CPS ensures continuous production with almost zero downtime of production means and intelligent real-time decision-making [2, 20, 21].

A cyber-physical system must be resilient to failures, for which various approaches are used. For example, from the perspective of organizing communication between the network of intelligent sensors or actuators, the architecture (Fig. 1) suggests the use of wireless sensor networks [22–25]. Wireless sensor networks find application in industrial automation systems for monitoring and control tasks. Their main advantage is flexible architecture and minimal costs for their implementation. An important feature of wireless sensor networks is their self-organization. Each individual node connects to a node located within the range of the antenna. Thus, a stable network is formed for organizing data transmission. Sensors and actuators combined into a wireless sensor network form a distributed system for collecting, processing, and transmitting information, which has self-organizing properties [25].

The use of a service-oriented approach in manufacturing management ensures the distribution of data from various sources in isolated structures and the construction of a decentralized control model, implemented through weak links between distributed processes. This maintains the autonomy of managing each process for each individual service [26, 27].

Cyber-physical systems [3] are intelligent systems that include networks of physical and computational components interacting with each other in the process of solving a common task. CPS and related systems (including the Internet of Things (IoT) and the Industrial Internet of Things) have great potential for creating innovative programs and influencing numerous economic sectors of the global economy. These interconnected and integrated systems provide new functions to improve the quality of life and technological progress in critically important areas such as healthcare, emergency prevention, management of transport flows in a smart city, intelligent manufacturing, defense, and national security, as well as energy supply and usage.

The conceptual model of CPS is shown in Fig. 2. This figure demonstrates the interaction of devices, systems, as well as systems within a system of systems (SoS). A CPS can be as simple as an individual device, or it may consist of one or several cyber-physical devices forming a system, or it can be a system within a system, consisting of multiple systems made up of multiple devices.

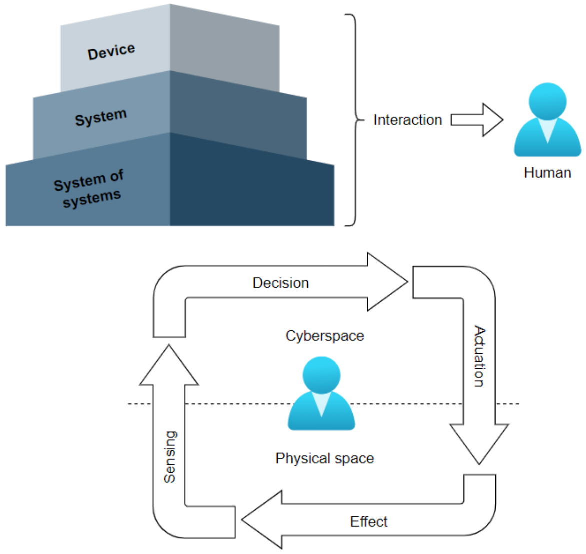


Fig. 2. Conceptual model of CFS

This model is recursive and perspective-dependent (i.e., a device from one perspective can be a system from another perspective) [1]. Ultimately, the CFS contains a decision stream along with at least one information or action stream. An information flow represents a digital measurement of the physical state of the physical world, while an action flow affects the physical state of the physical world. It allows collaboration from small and medium scale to city/country/world scale.

Ensuring stability of the distributed system

One of the approaches to ensuring the resistance of a distributed system to failures is the use of a switched system with parallel computing flows (Fig. 3) [27–29].

In Fig. 3 shows the parallel architecture of the organization of interaction between the components of the cyber-physical system, where several processes work simultaneously without certain connections between them. In this scheme, interaction is formed dynamically, by connecting processes through shared memory. All processes in the decentralized system [21, 25, 29–31] are performed in parallel and asynchronously, with different calculation speeds. In the notations of the cyber-physical system, this architecture provides for parallelization of processes organized by three groups of flows: measurement, calculation, and activation.

The approach to fault tolerance of information systems takes as input a CFS modeled by a transfer function and creates a robust equivalent system capable of controlling the same physical process using a switched linear control system. A switched system consists of a finite number of subsystems and a logical rule that controls switching between subsystems. It can be modeled as follows:

$$x_{k+1} = f_{\sigma(k)}\left(x_k, u_k\right), \tag{1}$$

where $k \in Z^+$ is time interval (Z set of natural numbers), $x \in R^n$ is the state of the decentralized system (R is a set of real numbers), $u \in R^p$ is input control, σ is a logical rule by which switching between subsystems occurs.

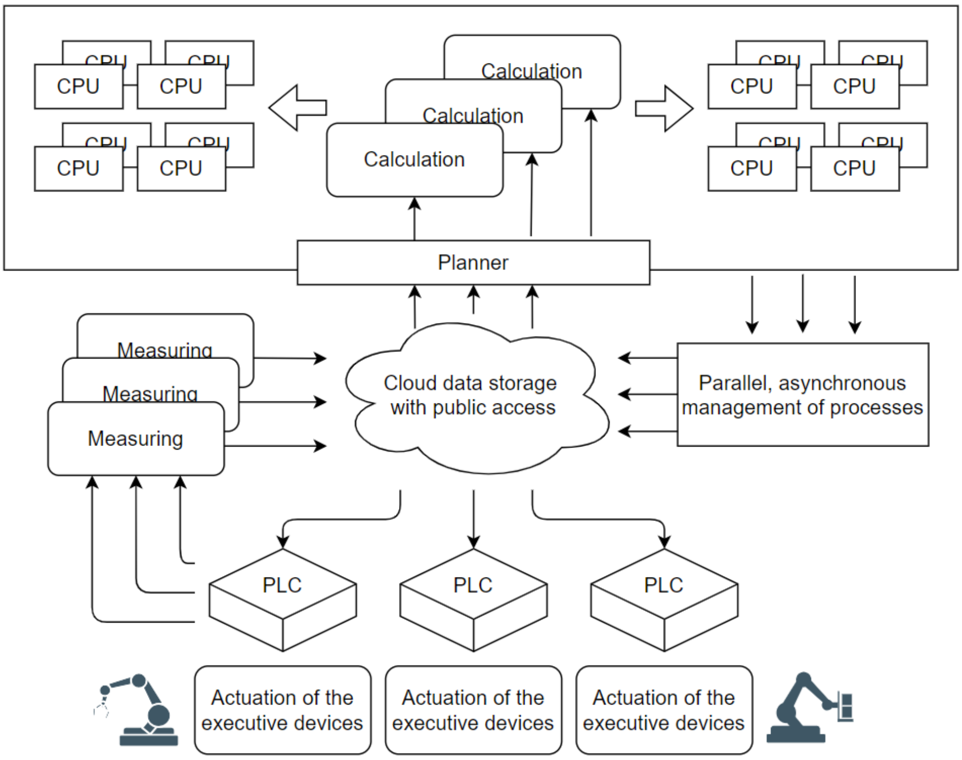


Fig. 3. Parallel architecture of the organization of interaction between the components of the cyber-physical system

The function f_σ maps the set of natural numbers Z^+ to the set of integers I:

$$\sigma : Z^+ \to I , \tag{2}$$

where $I = \{I,..., N\}$ is contains indexes of subsystems.

The subsystem is determined by the pair:

$$Sub = (M_i, G_i) , \tag{3}$$

where $M_i = \{A_i, B_i, C_i : i \in I\}$ is a set of physical system models, $G_i = \{V_i, E_i : i \in I\}$ is a set of graphs that represent network connections in a distributed communication system between intelligent hardware.

Thus, σ defines a switching signal between subsystems, which is a function of time (activated at time k) and determined by the process model and the topology of the sensor network. The physical model activated at time k is defined by the equation [31]:

$$x_{k+1} = A_{\sigma(k)} x_k + B_{\sigma(k)} u_k ,$$

$$y_k = C_{\sigma(k)} x_k , \tag{4}$$

where *A*, *B*, *C* are matrices of control models.

This approach consists in the development of distributed controllers that change over time the physical model they execute.

In the considered architecture, the overall production process is controlled by several independent controllers and is collectively a decentralized control system, i.e. if at time k the control model with matrices A_i, B_i, C_i is activated, then as a result we get a set of j controllers with $j \in 1..o$. Each controller will use a set of matrices A_{ij}, B_{ij}, C_{ij} :

$$A_i = \bigcup_{j=1}^{o} A_{ij} , \quad B_i = \bigcup_{j=1}^{o} B_{ij} , \quad C_i = \bigcup_{j=1}^{o} C_{ij} .$$

Thus, the controllers work only with a limited part of the general information.

To obtain different models to represent the general structure of the state space using the matrices A_{ij}, B_{ij}, C_{ij} , it is necessary to construct equivalent models starting from the initial transfer G(s).

This will make it possible to obtain different sets of controllers capable of managing the physical processes of a distributed system.

Using a set of matrices *A*, *B*, *C*, the mathematical model of a cyber-physical system can be written as follows [10]:

$$x_{k+1} = A x_k + B(u_k) + \omega_k , \tag{5}$$

where $x_k \in R^n$ is vector of state variables at the kth time step, $u_k \in R^p$ is control signal, ω_k is process noise, which can be described by white Gaussian noise, $A \in R^{n \times n}$ is state matrix, $B \in R^{n \times p}$ is input matrix of actuator signals.

The output signals of the system depend on the set of states x_k of sensors that are affected by noise υ_k :

$$y_k = C x_k + \upsilon_k , \tag{6}$$

where $C \in R^{m \times n}$ is matrix of output signals.

When CFS are used to manage technological processes in intelligent manufacturing, large data flows are used, coming from the network of sensors and reaching the executive mechanisms. These flows impose fundamental limitations on the performance and capabilities of CFS, as they require a large bandwidth and contribute to the rapid depletion of energy reserves during wireless communication. To overcome this limitation, it is necessary to consider the CFS as an implementation of a set of distributed information processing systems [31].

The principle of the decentralized process of managing physical processes in intelligent production with independent controllers and executive devices can be presented in the form of a functional diagram (Fig. 4) [32].

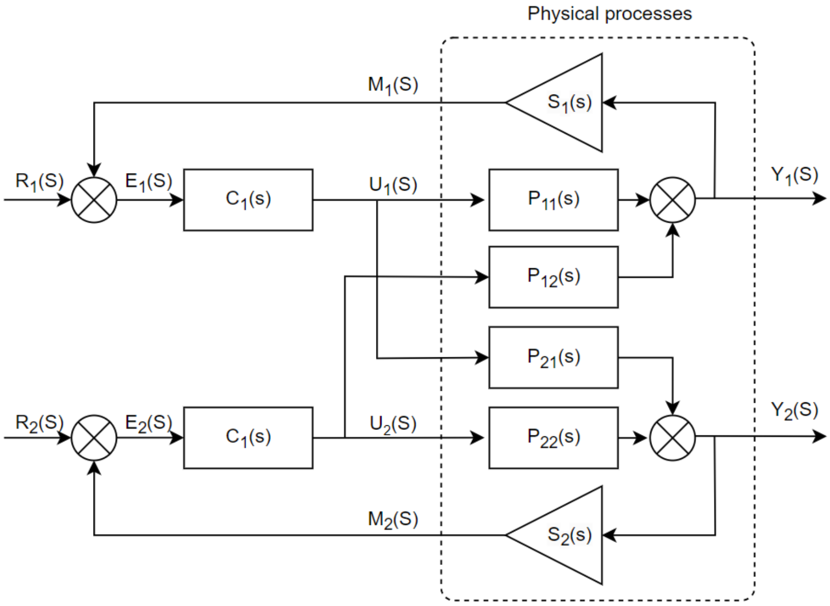


Fig. 4. The principle of the decentralized process of managing physical processes

This diagram describes a situation where industrial controllers of a distributed technological process manage specific executive devices. The executive devices affect the physical environment not only in their area of responsibility. For example, the ventilation control system regulates the microclimate condition in the production area, but at the same time, the dynamics of temperature change can affect the quality of the final product due to the dependence of technological regimes on its indicators. Thus, in the physical world, a controller managing one device or process influences the operation of another piece of equipment or process in the physical world.

The system has two inputs $R_1(s)$, $R_2(s)$ and two outputs $Y_1(s)$, $Y_2(s)$. In general, the output of the control unit $U(s)$ can be described by the following equation:

$$U(s)=\begin{bmatrix} U_1(s) \\ \vdots \\ U_q(s) \end{bmatrix}. \qquad (7)$$

The output signal $U(s)$ from the control unit takes into account the error $E(s)$:

$$U(s)=C(s)E(s). \qquad (8)$$

Physical processes controlled by a set of controllers can be described by the following equation:

$$P(s)=\begin{bmatrix} P_{11}(s) & \cdots & P_{1q}(s) \\ P_{21}(s) & \cdots & P_{2q}(s) \\ \vdots & \ddots & \vdots \\ P_{n1}(s) & \cdots & P_{nq}(s) \end{bmatrix}. \qquad (9)$$

The set of distributed controllers is written by the equation:

$$C(s)=\begin{bmatrix} C_{11}(s) & \cdots & C_{1q}(s) \\ C_{21}(s) & \cdots & C_{2q}(s) \\ \vdots & \ddots & \vdots \\ C_{n1}(s) & \cdots & C_{nq}(s) \end{bmatrix}. \qquad (10)$$

Thus, the output signal $Y(s)$ takes into account the signal from the control unit $U(s)$ and the effect of the operation of the physical process unit $P(s)$ and is described by the following equation:

$$Y(s)=P(s)U(s). \qquad (11)$$

Possible variants of output signals at the output of a distributed system can be presented in the form of a matrix:

$$Y(s)=\begin{bmatrix} Y_1(s) \\ \vdots \\ Y_q(s) \end{bmatrix}. \qquad (12)$$

At the same time, the set of input signals R(s) can be presented in the form of a matrix:

$$R(s)=\begin{bmatrix} R_1(s) \\ \vdots \\ R_q(s) \end{bmatrix} \qquad (13)$$

The measurement signals M(s), coming from the output of the sensors S(s), included in the feedback circuit, give the controllers information about the state of the executive devices:

$$M(s)=\begin{bmatrix} M_1(s) \\ \vdots \\ M_q(s) \end{bmatrix}. \qquad (14)$$

Thus, the sensor output signal M(s) takes into account the output signal Y(s) and the conversion factor of the sensor S(s) and can be described by the following equation:

$$M(s)=Y(s)S(s). \qquad (15)$$

The transition to full decentralization occurs with the use of decentralized controllers C(s) (Fig. 5) [32]:

$$C(s)=C'(s)D(s), \qquad (16)$$

where C'(s) is diagonal controller, D(s) is compensation block.

The compensation block D(s) can be represented as a distributed network to minimize interactions between processes. Thus, the decentralized controller C(s) produces signals V(s) that enter the input of the distributed network. As a result, each diagonal controller C'(s) controls n independent processes.

The distributed network $n \times n$ with $n=2$ is written in the form of a compensation matrix:

$$D(s)=\begin{bmatrix} 1 & D_{12}(s) \\ D_{21}(s) & 1 \end{bmatrix}. \qquad (17)$$

After the application of distributed controllers, the model of the decentralized control system of the cyber-physical system can be presented in the form shown in Fig. 6.

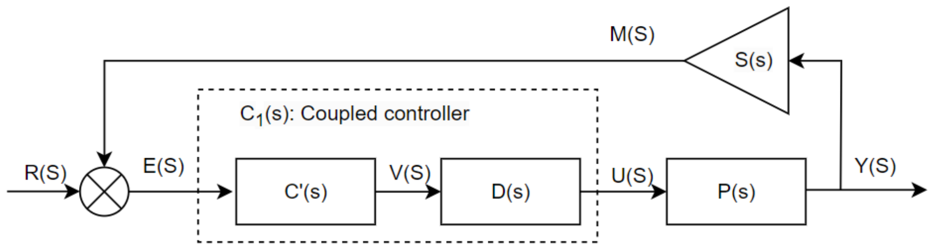


Fig. 5. Transition to a control system with a distributed controller

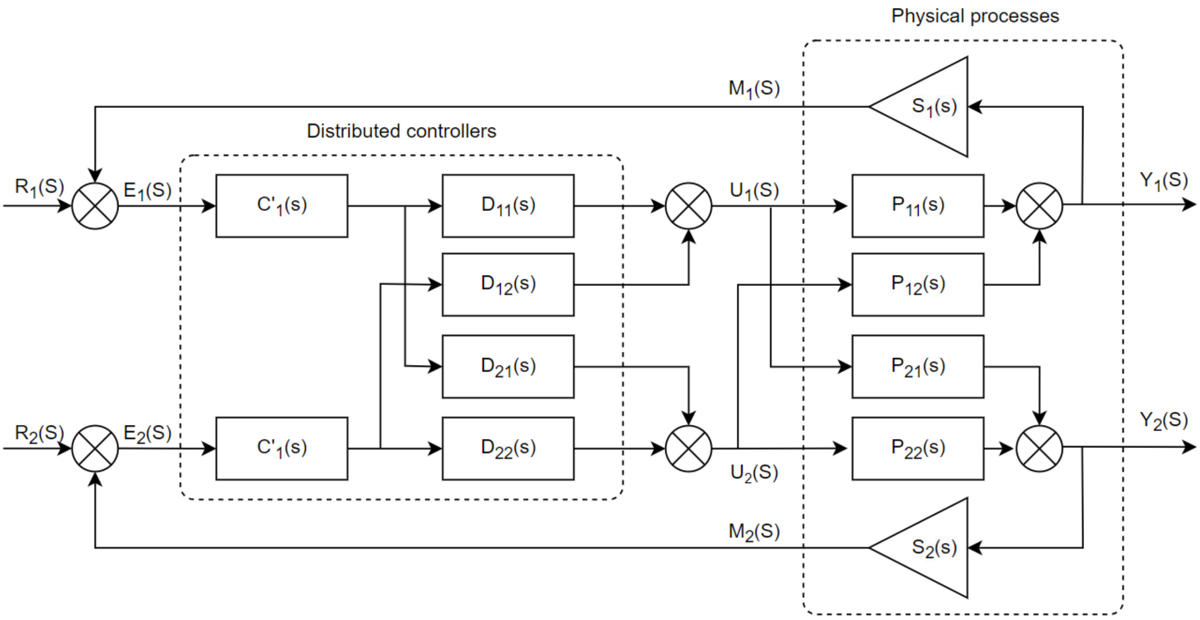


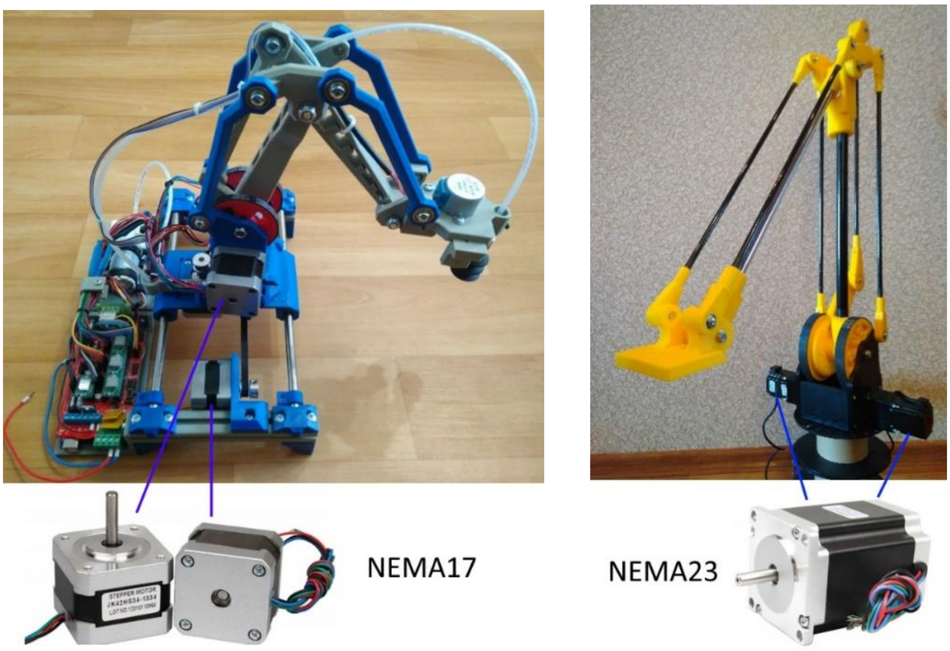
Fig. 6. Model of a decentralized cyber-physical system control system

Experimental research

Considering the dynamic nature of real processes, the standard mathematical description of models includes, in addition to algebraic relations, dependence on the accumulated (integral) effect of process variables and dependence on the rate of change (differential effect) of variables.

These two features define the dynamics of the object, and point to the fact that the behavior of a real process cannot be satisfactorily described without including its past history and how changes occur.

We will conduct experimental studies of the model of decentralized control of automation means at the production site. To build the model, we will use executive devices in the form of angular manipulator robots [33, 34]. The constructions of manipulators under consideration consist of two moving links and a rotating platform. The movement of the joints is performed by servo drives based on NEMA17 and NEMA23 stepper motors. In Fig. 7 shows the appearance of the manipulators.



а б

Fig. 7. Appearance of manipulators

In Fig. 7, a shows the design of a manipulator robot with four moving degrees of freedom based on NEMA17 stepper motors. A feature of the design is the ability to move the rails to the left and right. Each stepper motor implements a certain degree of freedom. The motors are controlled by the control module, which is built on the basis of the Arduino Mega controller.

In Fig. 7, b shows the design of the layout of an industrial manipulator robot with three moving degrees of freedom based on NEMA23 stepper motors.

In Fig. 8 shows the spatial reach zones of both angular-type manipulator designs.

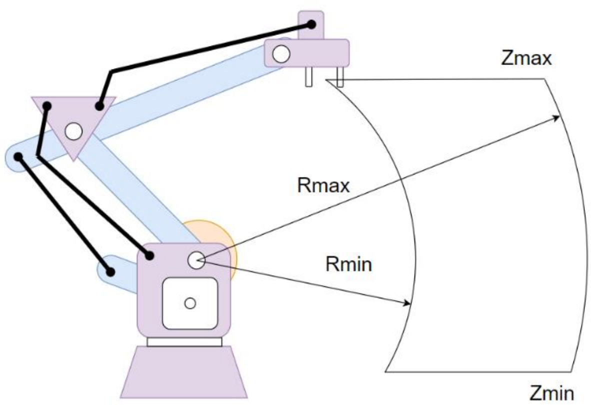


Fig. 8. Spatial zones of reach of the manipulator in the vertical plane

The spatial area of action of the manipulator in the vertical plane is limited by the design features of the device and in Fig. 8 is represented by the radii R_{min}, R_{max}, and the surface Z_{min} and Z_{max}. In the horizontal plane, the movement of the manipulator is limited by the radii R_{min}, R_{max}. Thus, we have a set of coordinates located within the range of the manipulator, which can be presented as follows:

$$M_{xyz} \in \left\{ R_{xyz}^{\min}, R_{xyz}^{\max}, Z_{xyz}^{\min}, Z_{xyz}^{\max} \right\} \tag{18}$$

Models can be reduced to the form of differential equations with continuous time, difference equations (with discrete time), or their combination (hybrid or impulse systems). These models connect the object's inputs with its individual outputs and deal with a limited description of the system in the process of its study.

As can be seen from Fig. 7, the main moving element of executive devices of robot manipulators as part of the CFS are servo drives. To simulate the behavior of a decentralized production site control system using manipulator robots, let's write down the main ratios for DC motors with independent excitation:

$$J\ddot{\theta}(t) = \tau_e(t) = k_1 i_a(t), \tag{19}$$

$$v_\omega(t) = k_2 \dot{\theta}(t), \tag{21}$$

$$i_a(t) = \frac{v_a(t) - k_2 \dot{\theta}(t)}{R}, \tag{22}$$

where J is moment of inertia of the motor shaft, $\theta(t)$ is rotation angle of the engine shaft, $\tau_e(t)$ is electric torque, k_1, k_2 are constants, $i_a(t)$ is motor armature current, $v_a(t)$ is armature voltage; R is armature resistance.

Combining these equations, we get the following model in the form of a second-order differential equation:

$$J\ddot{\theta}(t) = k_1\left[\frac{v_a(t) - k_2\dot{\theta}(t)}{R}\right] \quad (23)$$

This model can be presented as:

$$\frac{d}{dt}\begin{pmatrix}\theta(t)\\ \dot{\theta}(t)\end{pmatrix} = \begin{bmatrix}0 & 1\\ 0 & \dfrac{-k_1k_2}{JR}\end{bmatrix}\begin{bmatrix}\theta(t)\\ \dot{\theta}(t)\end{bmatrix} + \begin{bmatrix}0\\ \dfrac{k_1}{JR}\end{bmatrix}v_a(t)\,. \quad (24)$$

If we take $k_1 = JR$ and $k_2 = 2$, then using the properties of the Laplace transform to the model, we get:

$$\begin{aligned}&\frac{JR}{k_1}s^2\Theta(s) + k_2 s\Theta(s) - \\ &-\left(\frac{JR}{k_1}s + k_2\right)\theta\left(0^-\right) - \frac{JR}{k_1}\dot{\theta}\left(0^-\right) = V_a(s).\end{aligned} \quad (25)$$

If the initial conditions $\theta\left(0^-\right) = 0$, $\dot{\theta}\left(0^-\right) = 0$ and the input signal is a single step function applied at time $t = 0$, then

$$\begin{aligned}\Theta(s) &= \left(\frac{k_1}{JRs^2 + k_1k_2s}\right)V_a(s) = \\ &= \left(\frac{k_1}{JRs^2 + k_1k_2s}\right)\frac{1}{s}.\end{aligned} \quad (26)$$

Thus, the transmission characteristic of the system in its general form will be written as follows:

$$G(s) = \frac{k_1}{JRs^2 + k_1k_2s}. \quad (27)$$

Taking into account the value of the moment of inertia of the shaft and the resistance of the armature of the stepper motors used in the research (Table 1), and assuming constant coefficients $k_1 = k_2 = 1$, the structural diagram shown in Fig. 9.

Table 1 – **Characteristics of stepper motors of medium power**

Stepper motor model	Moment of inertia of the motor shaft, J, kg·m^2	Armature resistance, R, Ohm
NEMA23 JK57HS76-1006	0,00018225	8,6
NEMA17 JK42HS40-1704	0,0016	1,65
NEMA23 JK57HM76-2804	0,0324	1,15
NEMA17 JK42HS34-1334AC	0,000484	2,1

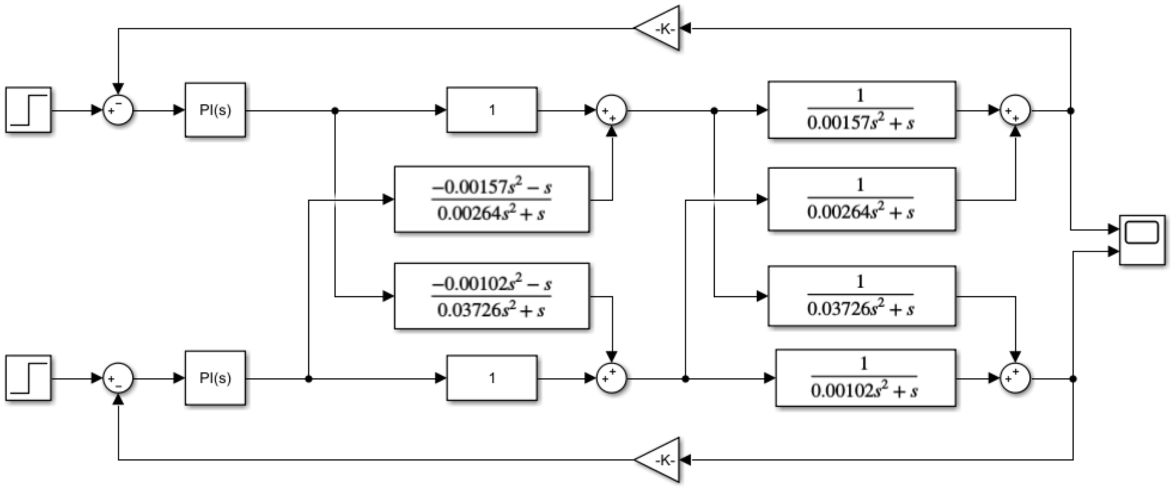


Fig. 9. Structural diagram of the experimental model of decentralized control of automation means

After performing the research, in Fig. 10 shows the transient characteristics of the developed model.

The conducted simulation showed that the system is stable and the output signal stabilizes in 0.14 ms, which is good for distributed systems of this type [32, 35–38].

Conclusions

This paper proposes the use of a model of decentralized management of cyber-physical systems in intelligent production. The main purpose of such a decision is to ensure the implementation of a technological process resistant to external influences to ensure the specified indicators of product quality.

Cyber-physical systems increase the efficiency of these processes thanks to the distributed structure of sensors and executive devices connected to each other by a decentralized information network of data transmission. Decentralized management of production processes provides real-time monitoring and control of the entire technological process in an intelligent factory, which provides opportunities to adapt production to meet customer needs. To ensure the stability of the distributed system, parallel decentralization of the control process is proposed and the architecture of the organization of interaction between the components of the cyber-physical system based on it is presented.

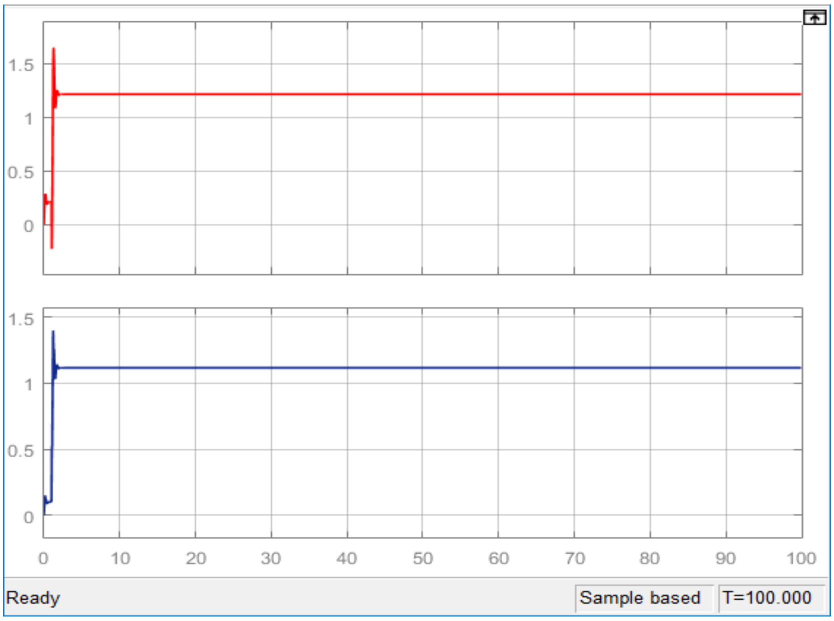


Fig. 10. Transient characteristics of the developed model

An intelligent manufacturing architecture has been built that combines physical space and cyberspace. The simulation of the decentralized control system of the production area using manipulator robots with an angular coordinate system based on servo drives, which act as stepper motors, was carried out. The cyber-physical system is presented as a distributed management process based on decentralized controllers. It is proposed to use the methods of describing linear dynamic systems for such controllers. The described structure is a multi-parameter controller consisting of a diagonal controller and a decoupling network in the form of a compensation block.

A feature of the proposed model is the consideration of sensors as part of the feedback of the decentralized control system. The result of the simulation is the stability of the decentralized cyber-physical system to external influences for the selected transient characteristics. Thus, the proposed approach best reflects the features of cyber-physical systems in the tasks of intelligent production management.

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Децентралізовані інформаційні системи в задачах управління інтелектуальним виробництвом

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Анотація. Об'єкт дослідження: процес розподіленого управління виробничими процесами в інтелектуальному виробництві. **Предмет дослідження:** модель децентралізованої системи управління технологічним процесом у виробничій зоні сучасного заводу з урахуванням концепції Індустрії 4.0. **Мета дослідження:** удосконалення методів управління інтелектуальними виробничими процесами для забезпечення стійкого до зовнішніх впливів технологічного процесу та забезпечення заданих показників якості продукції. Використовуються такі методи дослідження: методи аналізу та синтезу децентралізованих виробничих систем, методи моделювання та теорії автоматичного керування, математичний апарат теорії матриць, методи опису лінійних динамічних систем. Отримані **результати та висновки.** У даній роботі проведено моделювання децентралізованої інформаційної системи управління виробничою ділянкою інтелектуального виробництва за допомогою роботів-маніпуляторів з кутовою системою координат на основі сервоприводів, які виконують роль крокових двигунів. Для забезпечення стабільності розподіленої системи запропоновано паралельну децентралізацію процесу управління та наведено засновану на ній архітектуру організації взаємодії між компонентами кіберфізичної системи. Особливістю запропонованої моделі є врахування датчиків як частини зворотного зв'язку децентралізованої системи управління. **Результатом** моделювання є стійкість децентралізованої кіберфізичної системи до зовнішніх впливів для обраних перехідних характеристик.

Ключові слова: Індустрія 4.0; IoT; IIoT; інтелектуальне виробництво; кіберфізичні системи; робот; маніпулятор; децентралізована система управління.