ПРОБЛЕМНО І ФУНКЦІОНАЛЬНО ОРІЄНТОВАНІ КОМП’ЮТЕРНІ СИСТЕМИ ТА МЕРЕЖІ

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INFORMATION TECHNOLOGY OF VISUALIZATION FOR TECHNOLOGICAL PROCESSES FOR RESEARCH MODES OF FUNCTIONING OF COMPLEX TECHNOLOGICAL SYSTEMS

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Abstract. The development of a mathematical model of a technical system based on the means of discrete-continuous networks and taking into account the interaction with a multimedia platform is presented. The efficiency of the process for visualizing the functioning of the complex technical system is increased by implementing the interaction of the modeling environment with the Unity platform in the feedback mode. The experiments linked to the integration of the DC-Net simulation software environment with the Unity cross-platform development environment are implemented. An example of developing the model of a technical system in the DC-Net environment and an example of developing a process for visualizing the functioning of a corresponding technical system based on the Unity platform are presented. The fundamental suitability of using the integration of various information technologies linked with various software environments has been confirmed.

Keywords: hybrid systems, discrete-continuous networks, Unity, multimedia platform, Petri net.

INTRODUCTION

Information technology of visualization is going through the active stage of its development. This technology in technical and research applications enables the researcher to observe and correct the processes of functioning of a modulated object or system. At the same time, this possibility is based on mathematical and software support hidden from the researcher.

In the educational field, the technology of visualizing the process of mathematical modeling is especially valuable for the successful mastering of educational material in technical disciplines. Also, visualization technology is important for the acquisition of skills in practical work with complex technological systems (CTS) in which mechanical, thermal, chemical, electrical, hydraulic and other processes interact simultaneously [1–3].

Due to the increasing need for the use of interactive and distance learning such research is rather relevant.

Visualization of the technological process is essential when modeling a complex technical system. This complexity is caused by scientific and technical progress, leading to the emergence of new, more and more complex technological processes and complexes for which a qualitative analysis and appropriate control methods are required. Naturally, methods and means of visualization must be improved and developed in accordance with growing requirements.

The visualization technology of modeling processes for complex technical systems is available in almost all known software modeling. However, not all software tools are specialized in hybrid systems modeling [4, 5]. The theory of discrete-continuous networks was proposed for modeling and research of such hybrid systems in 1990–1993 [3]. The corresponding program DC-Net was developed in the Windows environment based on this theory. This program allows for visualized editing of systems models represented by means of discrete-continuous networks.

In addition to the development of the theory of discrete-continuous networks and the DC-Net environment, the MATLAB / SIMULINK / SIKOSS software complex stands out. This complex also provides for the use of special methods for the synthesis of complex systems, but the MATLAB / SIMULINK / SIKOSS complex has its drawbacks [3].

Despite the lack of specialized tools of discrete-continuous networks the MATLAB / SIMULINK have great capabilities in the field of modeling complex technical systems. But in the field of technology for visualization of technological processes, the undisputed competitor is the tool package LabVIEW [6, 7]. However, the LabVIEW environment has its own process visualization format and its own methods for developing virtual instruments and models of control systems.

The undeniably high visualization capabilities of various processes and mathematical models is the Unity environment [8]. This environment is a cross-platform development environment for computer games.

It is obvious that the greatest efficiency can be obtained by combining the capabilities of various specialized software tools [9–11]. For example, a combination of the DC-Net program, which is specialized in modeling complex technical systems, and the Unity environment, which provides the ability to efficiently visualize the modeling processes. Accordingly, the work linked with the development of some visualization information technology based on a combination of various methods and tools of software is relevant.

The purpose of the scientific work is to increase the efficiency of the visualization process of the functioning for complex technological complexes by implementing the interaction of the modeling environment with the Unity platform in the feedback mode.

PROBLEM STATEMENT

In order to achieve this purpose we need to develop a mathematical model of a complex technical system based on the means of discrete-continuous networks, taking into account the use of feedback functions from a multimedia platform. Such multimedia platform provides visualization of the functioning of the complex technical system.

The development of such a model involves the formation of a structure and an algorithm for the operation of the complex of modeling, taking into account the feedback functions from the Unity platform to the mathematical model represented by DC-Net tools.

Ultimately, it is important to implement the developed schema using a real example. It is important to establish the fundamental suitability of the complex of modeling and it is also important to determine and confirm its advantages over the analogs developed by the authors earlier.

MATERIALS AND METHODS

A multimedia platform for visualizing the functioning of the CTS is linked with a virtual machine. This virtual machine is an integral part of the multimedia platform and at the same time it can represent a certain model of a complex system.

For example, a description of the dynamic process of the functioning of the CTS in ActionScript 3.0 allows further visualization of the corresponding processes, however, there is a high laboriousness of creating such a visualization system. It is obvious that the creation of a CTS model by means of the DC-Net environment is a less laborious process. But in this case, to integrate the multimedia platform and the DC-Net software environment, it is necessary to present some kind of information technology. The block diagram of the visualization system of the corresponding information technology is shown in Fig. 1. As an example, a not so complex system is considered in Fig. 1. The functioning of such a system can be represented by a corresponding Petri net and some animation fragment. This fragment represents the corresponding apparatus for the production of insulated copper wire.

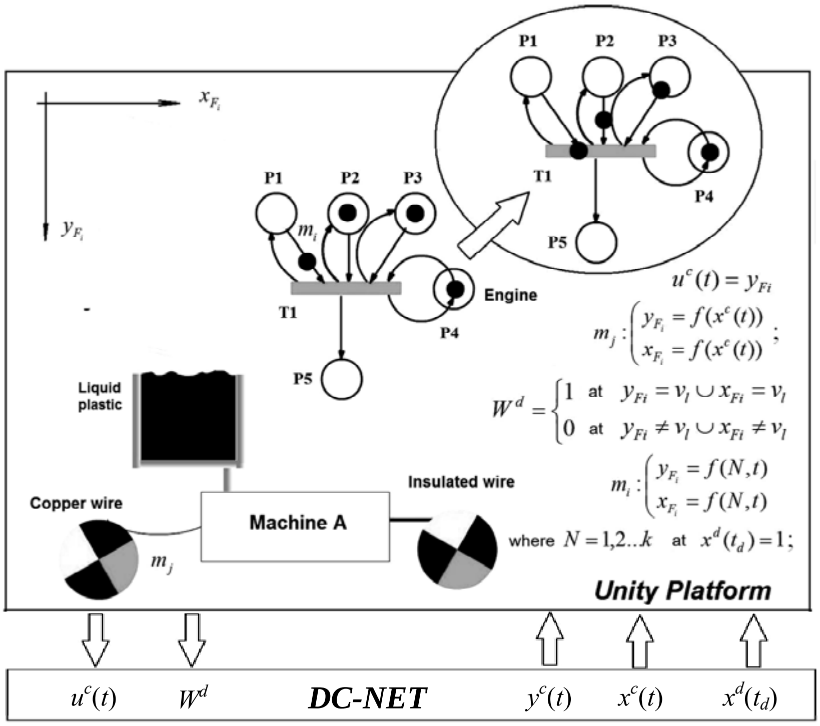

Fig. 1. Representation of CTS by means of discrete-continuous networks with feedback from a multimedia platform

In this direction, it is important to implement the movement of visualization objects m_i, defined in the Unity shell, which represents the corresponding multimedia platform. At the same time, the movement of visualization objects m_i, in the field of coordinates y_{F_i}, x_{F_i} depends on the variables $y^c(t)$, $x^c(t)$, $x^d(t)$ according to the expressions presented in Fig. 1. The relationship between the visualization process and the operation of technological equipment is presented in Fig. 1. The functioning of the formed Petri net according to the variables $y^c(t)$, $x^c(t)$, $x^d(t)$ obtained from the DC-Net environment in Unity is also presented.

Thus, DC-Net simulates the necessary dynamic system and the multimedia platform dynamically displays the necessary information and visualizes the process of this system functioning.

In this example, the object of animation is a technological machine consisting of equipment of continuous and discrete nature. The machine produces insulated copper wire from bare wire and plastic. The constituent elements of the machine are discrete and continuous. Discrete elements are starting and stopping the machine. Continuous elements are the movement of a copper wire and changes in the level of liquid plastic in a container.

The functioning of the machine model is also represented by a Petri net, consisting of *P1, P2, P3, P4* positions and *T1* transition.

Marking of position *P1* means the presence of liquid plastic in the tank, marking position *P2* means the presence of a copper wire, marking position *P3* means the presence of an insulated wire. If machine A fails or at least one mark is missing, then the production of the insulated wire is stopped. In this case, the transition *T1* does not work and the engine cannot start.

The main load on the development of the CTS simulation model is assumed by the DC-Net graphic editor. In this case, the CTS model which is represented by means of discrete-continuous networks together with a decision-making device looks like shown in Fig. 2.

The continuous-event part of the system, represented by a discrete-continuous network, is described by the following equations of state and the output $\bar{x}^c(t) = \bar{u}^d(t_k)\lambda_i(x^c(t), u^c(t))$, $\bar{y}^c(t) = \bar{u}^d(t_k)\lambda_i(x^c(t))$ with a variable right-hand side for the formation of a continuous state $\bar{x}^c(t)$, where $\bar{u}^d(t_k) =$ $= f(y^d_л(t_л))$ is the vector function of controlling the operating modes, $u^c(t)$ is the continuous control vector.

The discrete-continuous part is represented by the following equations of state and output of the discrete subnet of the discrete-continuous network: $x^d_V(t_к) = \lambda(x^d_{V-1}(t_к), u^d_л(t_к))$, $y^d_л(t_к) = \Lambda x^d_V(t_к)$, where $u^d_л(t_к)$ is the input action for the logical part, $x^d_V(t_к)$ is the discrete vector of state (Λ is transition matrix). The generated state vector $x(t) = (x^c(t), x^d(t))^{\mathrm{T}}$ is needed in the future to control the visualization process.

Thus, in the DC-Net software environment, a state vector $F_{In} = [\bar{x}_c(t), \bar{x}_d(t_k)]$ is formed, which is enters in the transfer format of the vector of continuous $X_c(t)$ and $X_d(t_k)$ discrete variables from DC-net to the Unity program, where $\bar{u}_{dl}(t_k)$ is the vector of discrete-event states from the continuous-event part to the discrete-event part of the model in DC-Net.

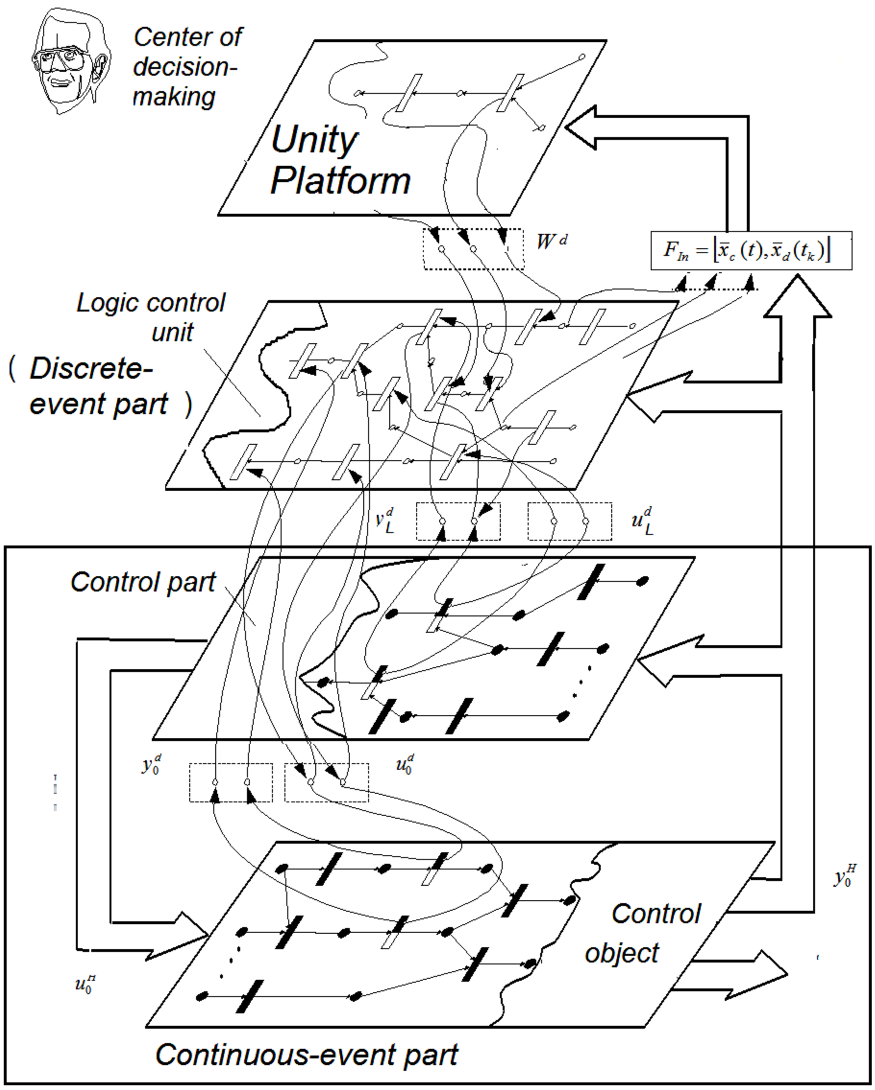

Fig. 2. Representation of CTS by means of discrete-continuous networks

In the same way, the reverse transmission vector from Unity to DC-net is formed $F_{\text{out}} = [\overline{u}_c(t), \overline{w}_d(t_k)]$, where $u^c(t) = y_{Fi}$, $\overline{w}_d(t_k) = \left| w_1^d \quad w_2^d \quad \ldots \quad w_n^d \right|^{\mathrm{T}}$ is vector of discrete-event states from Flash to discrete-event part model in DC-Net, where in

$$w_i^d = \begin{cases} 1, & y_{F_i} = v_l \cup x_{F_i} = v_l; \\ 0, & y_{Fi} \neq v_l \cup x_{F_i} \neq v_l, \end{cases}$$

y_{F_i}, x_{F_i} is coordinates of the i-th object in the Unity — visualization window.

Accordingly, in the Unity-visualization window, the movement of objects m_i or m_j corresponds to the coordinates y_{F_i}, x_{F_i} according to the following expressions:

$$m_i:\begin{cases} y_{F_i} = f(N,t); \\ x_{F_i} = f(N,t), \end{cases} \quad N = 1, 2, ..., k,$$

if $x^d(t_d) = 1$ then

$$m_j:\begin{cases} y_{F_i} = f(x^c(t)); \\ x_{F_i} = f(x^c(t)). \end{cases}$$

Closing the parts of the discrete-event part and continuous-event part is realized by means of the vector $\overline{u}_{do} = \Lambda \overline{x}_d(t_k)$.

The elements of this vector discretely change the coefficients of the equations representing the continuous-event part of the model, which is implemented by means of DC-Net.

Thus, DC-Net simulates the necessary dynamic system, and Unity platform dynamically visualizes the process of this system functioning.

For the correct interaction of two environments with different hierarchies and principles of operation, the format of data transfer between systems had to be standardized. The block diagram of the data exchange algorithm between DC-Net and Unity is shown in Fig. 3. This algorithm determines the required values of variables for animation of the process depending on the time interval of data exchange Δt.

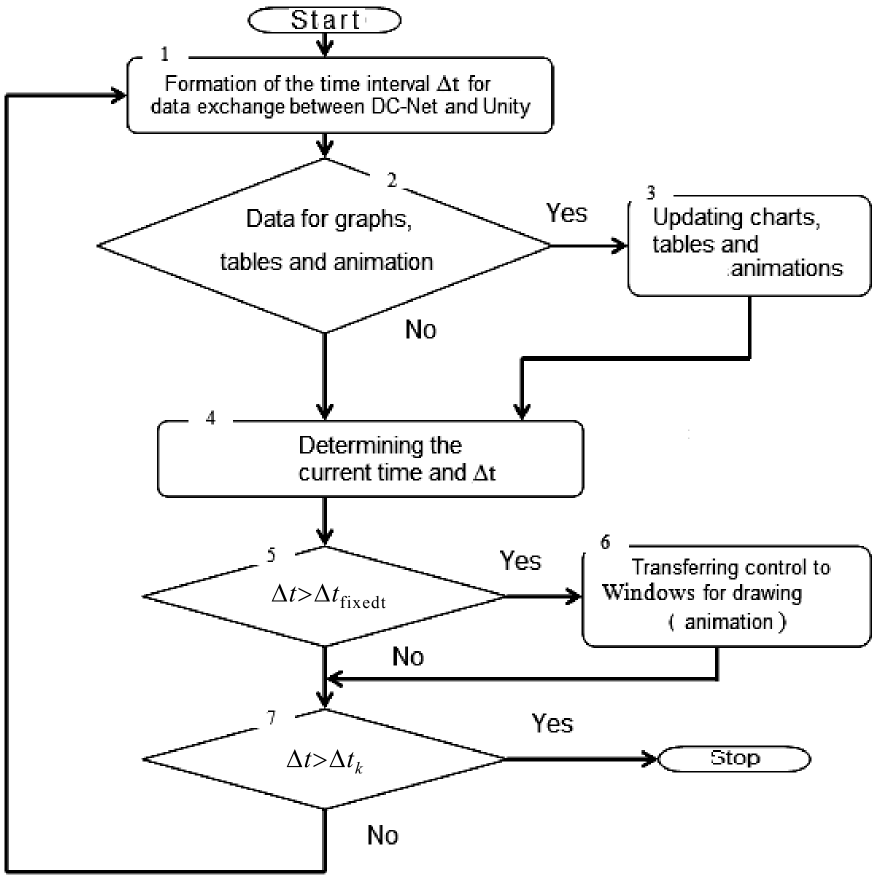

Fig. 3. Blok-diagram of the data exchange algorithm between Unity and DC-Net

A method for organizing the vector of transfer of continuous and discrete variables from DC-Net to Unity was also proposed to develop communication between systems. These systems are combined into a single information technology in which the DC-Net modeling system generates a parametric data transfer file.

EXPERIMENTS

In the software integrated environment DC-Net – Unity all necessary experiments were carried out. To carry out an experiment, it is initially necessary to realize a model of the investigated object in the software environment.

The continuous-event part of the mathematical model of the apparatus for the production of an insulated wire is represented by the following equation in matrix-differential form:

$$\overline{X}_L(t|t_k|) = B_0\,\Xi(u_{0d}(t_k))\,\overline{u}_c(t),$$

where

$$\overline{X}_L(t|t_k|) = \left|\frac{d}{dt}X_L(t|t_k|) \quad \frac{d}{dt}X_m(t|t_k|)\right|^{\mathrm{T}},$$

$$\overline{X}_L(t|t_k|) = \left|\frac{d}{dt}X_L(t|t_k|) \quad \frac{d}{dt}X_m(t|t_k|)\right|^{\mathrm{T}},$$

$$B_0 = |B_{01} \quad B_{02} \quad B_{03} \quad B_{04}|,$$

$$B_{01} = \begin{bmatrix} 5 & 0 \\ 0 & 500 \end{bmatrix},\ B_{02} = \begin{bmatrix} 0 & 0 \\ 0 & 500 \end{bmatrix},\ B_{03} = \begin{bmatrix} 5 & 0 \\ 0 & 0 \end{bmatrix},\ B_{04} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

are constant matrices of the corresponding dimension $(n \times m)$,

$\Xi(u_{0d}(t_k)) = |\xi_1 \quad \xi_2 \quad \xi_3 \quad \xi_4|$ is vector of modes control;

$$\xi_1 = \begin{cases} 1 & \text{at} \quad u_{od}(t_k) = |\mu(p_1) \quad \mu(p_2)| = |0 \quad 0|, \\ 0 & \text{at} \quad u_{od}(t_k) \neq |\mu(p_1) \quad \mu(p_2)| = |0 \quad 0|; \end{cases}$$

$$\xi_2 = \begin{cases} 1 & \text{at} \quad u_{od}(t_k) = |\mu(p_1) \quad \mu(p_2)| = |1 \quad 0|, \\ 0 & \text{at} \quad u_{od}(t_k) \neq |\mu(p_1) \quad \mu(p_2)| = |1 \quad 0|; \end{cases}$$

$$\xi_3 = \begin{cases} 1 & \text{at} \quad u_{od}(t_k) = |\mu(p_1) \quad \mu(p_2)| = |0 \quad 1|, \\ 0 & \text{at} \quad u_{od}(t_k) \neq |\mu(p_1) \quad \mu(p_2)| = |0 \quad 1|; \end{cases}$$

$$\xi_4 = \begin{cases} 1 & \text{at} \quad u_{od}(t_k) = |\mu(p_1) \quad \mu(p_2)| = |1 \quad 1|, \\ 0 & \text{at} \quad u_{od}(t_k) \neq |\mu(p_1) \quad \mu(p_2)| = |1 \quad 1|; \end{cases}$$

$\overline{u}_c(t) = |u_1(t) \quad u_2(t)|^{\mathrm{T}}$ is input vector.

The discrete event part of the model is described by the following equation:

$$\overline{x}_d(t_k) = \overline{x}_d(t_{k-1}) + |W|V + W_d(t_k) + u_{dt}(t_k),$$

where $\overline{u}_{dl}(t_k) = |\, f_{c/d}(X_L) \quad f_{c/d}(X_m) \quad 0 \quad \ldots \quad 0\,|^{\mathrm{T}}$ is vector of discrete-event states from the continuous-event part to the discrete-event part of the DC-Net model;

$|W|$ is an $n \times m$ matrix, the incidence matrix of Petri net;

$\overline{w}_d(t_k) = \left| w_1^d \quad w_2^d \quad \ldots \quad w_n^d \right|^{\mathrm{T}}$ is vector of discrete-event states from Unity to discrete-event part of the model in DC-Net.

The discrete-continuous network editor window of the DC-Net program is shown in Fig. 4. This editor realized a diagram of a model of an insulated wire production apparatus.

The $X_L(t)$, $X_m(t)$, $u_1(t)$, $u_2(t)$ variables and t_{13}, t_{23}, t_{33} structure-controlled transitions of a discrete-continuous network are denoted in Figure 4. The structure-controlled transitions provide a change in the coefficients of the matrix B_{0i}, $i = 1,\ldots,4$.

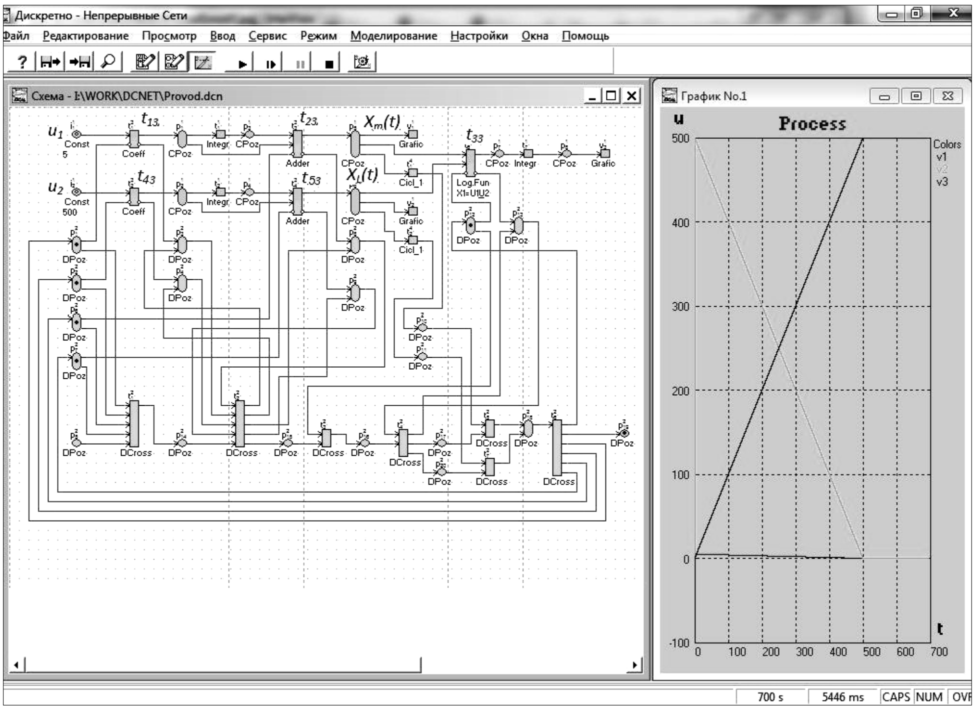

Fig. 4. A fragment of the model diagram implemented by means of the DC-Net environment

RESULTS

As a result of the work performed, a demonstration animation of the process in functioning of the apparatus for the production of insulated wires was realized. Also, visualization of the Petri net functioning was presented in parallel on the same animation screen. This Petri net shows the work of the corresponding apparatus. Thus, it is possible to obtain graphical information about changes in the parameters of a modeled object and its world linked with visualization (steam extraction, color change, etc.) [12].

Ultimately, the requirements for the developed visualization system for the modeling process were met.

DISCUSSION

The research results confirmed the assumptions that the introduction of feedback from the visualization system to the model significantly expands the capabilities of the developed information technology of visualization. It is obvious that such information technology is necessary for distance learning and it is also possible to find new applications of such technology.

Considering the above mathematical apparatus, one should focus on the W_i^d vector of discrete-event states of the model. Such vector is linked with specific operations of creating feedback for DC-Net. This makes it possible to implement the construction of new models. At the same time, additional structured transitions are introduced into DC-Net for the further formation of a hierarchical system together with the Unity platform. Feedback from this platform is shown in Fig. 1.

CONCLUSIONS

The scientific novelty of the results. The problem linked to with the development of the mathematical model of a technical system based on the means of discrete-continuous networks, taking into account the use of feedback functions from the Unity platform was solved in the present work.

Thus the method of organizing the structure and formate of transferring the vector of variables of the CTS model from the simulation software to the multimedia platform and vice versa has got the further development.

The practical significance of the results. The developed methods for the synthesis of CTS models based on an integrated multimedia platform and means of discrete-continuous networks make it possible to implement a practical problem. This practical problem is linked with the implementation of virtual simulators of distance learning systems.

The prospects for further research. Further development of the scientific direction must be directly related to the formation of mathematical models for the automated formation of algorithms or Petri nets within the framework of modern intelligent technologies.

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INFORMATION ON THE ARTICLE

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ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ ВІЗУАЛІЗАЦІЇ ТЕХНОЛОГІЧНИХ ПРОЦЕСІВ ДЛЯ ДОСЛІДЖЕННЯ РЕЖИМІВ ФУНКЦІОНУВАННЯ СКЛАДНИХ ТЕХНОЛОГІЧНИХ СИСТЕМ / А.В. Денисенко, О.О. Гурский

Анотація. Подано розвиток математичної моделі технологічної системи на основі засобів дискретно-неперервних мереж і з урахуванням взаємодії з мультимедійною платформою. Забезпечено підвищення ефективності процесу візуалізації функціонування складної технологічної системи за рахунок реалізації взаємодії середовища моделювання з платформою Unity в режимі зворотного зв'язку. Реалізовано експерименти, що пов'язані з інтеграцією програмного середовища моделювання DC-Net з інструментом для розроблення багатовимірних додатків Unity. Наведено приклад розроблення моделі технічної системи в середовищі DC-Net і приклад розроблення процесу візуалізації функціонування відповідної технічної системи на основі платформи Unity. Підтверджено принципову придатність використання інтеграції різних інформаційних технологійб пов'язаних з різними програмними середовищами.

Ключові слова: складні технологічні системи, дискретно-неперервні мережі, Unity, мультимедійна платформа, мережі Петрі.

ИНФОРМАЦИОННЫЕ ТЕХНОЛОГИИ ВИЗУАЛИЗАЦИИ ТЕХНОЛОГИЧЕСКИХ ПРОЦЕССОВ ДЛЯ ИССЛЕДОВАНИЯ РЕЖИМОВ ФУНКЦИОНИРОВАНИЯ СЛОЖНЫХ ТЕХНОЛОГИЧЕСКИХ СИСТЕМ / А.В. Денисенко, А.А. Гурский

Аннотация. Представлено развитие математической модели технологической системы на основе средств дискретно-непрерывных сетей и с учетом взаимодействия с мультимедийной платформой. Обеспечено повышение эффективности процесса визуализации функционирования сложной технологической системы за счет реализации взаимодействия среды моделирования с платформой Unity в режиме обратной связи. Реализованы эксперименты, связанные с интеграцией программной среды моделирования DC-Net с инструментом для разработки многомерных приложений Unity. Приведен пример разработки модели технической системы в среде DC-Net и пример разработки процесса визуализации функционирования соответствующей технической системы на основе платформы Unity. Подтверждена принципиальная пригодность применения интеграции различных информационных технологий, связанных с различными программными средами.

Ключевые слова: сложные технологические системы, дискретно-непрерывные сети, Unity, мультимедийная платформа, сети Петри.