Розглядається використання штучних нейронних мереж до синтезу інтелектуальних систем з синергетичним законом керування. Показано, що досі всі об'єкти дослідження, а відповідно і закони керування, вважали лінійними, або намагались звести їх до таких, втрачаючи в певних особливостях. Проте, як свідчить практика, реальні об'єкти у своїй більшості, є нелінійними. Розгляд таких об'єктів із спробою їх лінеаризації призводить до того, що втрачаються важливі характеристики всього процесу. Основна частина тепличного комплексу складається саме із нелінійних об'єктів керування. Не винятком стала і теплиця та кожен технологічний процес окремо.

Запропоновано основні положення синергетичного підходу до проблеми системного синтезу. Показано синергетичний синтез закону керування тепличним комплексом в умовах не контролюючих змін технологічних параметрів та зовнішніх збурень. Використаний математичний апарат нечіткої логіки дає можливість реалізації нечіткого керування. Особливо позитивно це проявляється за умов, коли процеси є складними для аналізу на основі використання традиційних кількісних методів. А також, коли інформація, що поступає про об'єкт, неякісна, неточна або невизначена. Саме така інформація надходить для аналізу та її подальшого використання, при вирощуванні овочевої продукції у тепличних комплексах. Запропонований алгоритм синтезу нейромережевого регулятора для тепличного комплексу на основі заданого синергетичного закону керування. Алгоритм базується на поведінці синергетичного регулятора, що моделює значення температури та вологості штучною нейронною мережею в результаті її навчання. Особливість запропонованого комплексного підходу до синтезу інтелектуальної системи керування тепличним комплексом полягає в комбінації принципу єдності процесів самоорганізації та навчання нейронної мережі на попередньому етапі. Завдяки такому поєднанню, забезпечується подальше стійке функціонування системи інтелектуального керування вирощування овочевої продукції

Ключові слова: синергетичний регулятор, нейронна мережа, інтелектуальне керування, тепличний комплекс, овочева продукція

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MANAGING A GREENHOUSE COMPLEX USING THE SYNERGETIC APPROACH AND NEURAL NETWORKS

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1. Introduction

A distinctive feature in managing current neural networks is the presence of an appropriate set of direct and inverse relationships. Intelligent management of a greenhouse complex must take into consideration that the application of intelligent control systems is based on the principles listed below, as confirmed by studies that addressed the neuro-fuzzy systems to control energy consumption at greenhouses and biotechnological facilities [1, 2]:

– the presence of a close informational interaction between control systems and actual external environment and the use of specially organized information communication channels;

– principal openness of the systems in order to enhance intelligence and improve their own performance;

– the existence of mechanisms to predict the external world and their own performance across the dynamic world of innovation;

– building a management system in the form of a multilevel hierarchical structure in accordance with the rule: improving intelligence while reducing requirements to accuracy as the rank of the hierarchy increases;

– maintaining operation at a disruption in communication or at a loss of controlling influence from the higher levels of hierarchy of the governing structure.

By accounting for these principles, the systems of this kind could be synthesized by achieving the combination of processes of self-organization and management, namely, through using, in order to synthesize intelligent control systems, the synergistic approach.

Such an approach is most similar to the applied theory of management that implies a transition from the initial task, including managing the object of control and an external force. The next stage forms an expanded statement of the task such that external forces become internal interactions within a general (closed) system. To do this, external influences are represented as partial solutions to some additional differential equations that describe an information model, thereby exercising their "immersion" into the general structure of the extended system [3].

In this case, an important issue for the synthesized control system is the robustness of its functioning. This is defined in part by the principle of preserving the operation at a loss of communication. A given task could be solved as a result of separating the internal processes of functioning of a greenhouse complex, which could be achieved by using a neural network technology. This indicates the relevance of our research aimed at intelligent management of a greenhouse complex using the synergistic approach and artificial neural networks.

2. Literature review and problem statement

Paper [4] proposed a synergistic approach to managing complex technological facilities, to defining and describing the areas to attract the attractor as the centers that form dissipative space-time structures. The reported research results allow the estimation of performance of a complex system from the point of view of self-organization for the case of chaotic influences, both external and internal. However, the issue on the synergistic control over complex systems remains to be resolved, namely managing a greenhouse complex. The reason for this may be that special attention should be given not to the force of action on the system but rather to considering the accuracy and character of information support to decision making [1, 5]. It is the accuracy of information support for decision-making that defines an efficient organizational and technical structure.

Synthesis of effective management strategies to control non-linear systems was examined by using the methods pacification [5], backstepping [6, 7], robust [8, 9] and synergistic control [5, 10]. Among them, the most promising for complex greenhouse facilities are the methods of synergistic control, discussed in papers [10–12]. From the point of view of unresolved issues within the framework of the current study, these papers described the algorithm of adaptive control over nonlinear systems, the application of an integrated synergistic approach to complex non-linear objects, as well as successful implementation of the proposed solutions. All this gives grounds to assert that it is expedient to apply a given approach, which makes it possible to consider the physical and chemical features of technological processes, to reflect the phenomena of natural self-organization. Application of a set of the synergistic approach and artificial neural networks provides for resource-saving modes of operation. These operation modes are characterized by resistance against external perturbations, structural and parametric changes, in addition they make it possible to organize an efficient search for target states under different conditions. The resource-saving modes of operation are distinguished by the necessary flexibility at modifying goals and task variation, they have high reliability and ability to avoid emergencies [5, 13]. Still unresolved are issues on optimal planning and synergistic control over multi-parametric objects that have the input, output, and disturbing coordinates.

Paper [10] describes modern approaches to methods for managing an object based on the synergistic approach. If control is carried out by changing parameters of the order, the result of such actions would be the instability, symmetry disruption, as well as break in the boundaries of a complex nonlinear system. Consequently, there could be several possible scenarios of system performance after a phase transition. For the case of control by modifying the initial conditions there is a possibility for the system to develop in multiple directions, including a chaotic performance. The difficulty of such an approach is that it is not always possible to change the initial conditions. Sometimes the regulation is strict. Each of these methods is used when it is impossible to apply another. Thus, if there is a prospect, given a set of characteristics and parameters for the system, to define the set of parameters of order, and there is no any possibility to change input conditions, then control is executed by changing the parameters of order. If the set of parameters is too large, or one cannot define them through complex inter-relationships within the system, it is necessary to use control by modifying the initial conditions.

Moreover, study [2] has been shown that these methods produce satisfactory results for the models of actual systems subject to idealization. All this gives grounds to assert that it is expedient to study new approaches to the management of complex non-linear technological systems such as a greenhouse complex. This part of the task could be solved by combining the proposed synergistic approach and artificial neural networks. The task is based on the synthesis of a neural network controller based on a dynamic controller with the synergetic control law (in parallel with a sequential consideration of invariant multi-images of control over values for temperature and humidity of the internal air at a greenhouse) and could be solved by training an artificial neural network of the preset configuration.

3. The aim and objectives of the study

The aim of this study is the synthesis of an intelligent control system for a greenhouse complex using the synergistic approach and artificial neural networks. The proposed approach would provide the necessary possibilities for practical research and for applying the results in order to predict subsequent performance of an object and, in the future, in order to devise effective resource-saving control strategies for a greenhouse complex.

To accomplish the aim, the following tasks have been set:

– to construct control laws that would ensure optimal control over operational modes of a greenhouse;

– to synthesize a neural network controller for a greene house complex;

– to synergistically synthesize a greenhouse complex controller.

4. Procedure for constructing control laws for a greenhouse complex

Mathematical model (1), (2) describes changes in the temperature and humidity of inside air in a greenhouse [14]:

$$\frac{dT_{ins}(t)}{dt}=\frac{1}{\rho C_a V_t}\left[Q_h(t)+S_a(t)-\lambda Q_f(t)\right]-$$
$$-\left(\frac{\nu_v(t)}{V_t}+\frac{k_{t.gr.}}{\rho C_a V_t}\right)\left[T_{ins}(t)-T_{out}(t)\right],$$

$$\frac{d\varphi_{ins}(t)}{dt}=\frac{1}{V_r}Q_h(t)+\frac{1}{V_r}\left[ES_a(t),\varphi_{ins}(t)\right]-$$
$$-\frac{\nu_v(t)}{V_r}\left[\varphi_{ins}(t)-\varphi_{out}(t)\right], \quad (1)$$

$$E\left[S_a(t),\varphi_{ins}(t)\right]=\alpha\frac{S_a(t)}{\lambda}-\beta\varphi_{ins}(t), \quad (2)$$

where T_{ins}, T_{out} is the air temperature inside and outside a greenhouse, respectively, (°C);

φ_{ins}, φ_{out} is the relative air humidity inside and outside a greenhouse, respectively, (%);

$k_{t.gr.}$ is the coefficient of heat transfer for a greenhouse enclosure (W/K);

V is the full geometric volume of a greenhouse, (m^3);

V_t, V_r is the volume of air that is heated and moistened, respectively (m^3).

It is typically 60–70 % of the total volume of a greenhouse.

ρ is the air density (1.2 kg/m^3);

C_a is the heat capacity of air (1.005 kJ·kg^{-1}·K^{-1});

Q_h is the power of air heating system in a greenhouse, (W);

Q_f is the performance of a fogging system, (g water/s);

S_a is the solar radiation absorbed by a greenhouse (W);

λ is the heat of vaporization, (2,256 kJ/kg);

ν_v is the air exchange, provided by a system of ventilation, (m^3/s);

$E[S_a(t), \varphi_{ins}(t)]$ is the evapotranspiration of plants as a function of the absorbed solar radiation and air humidity in a greenhouse (g water/s);

α, β are scale ratios.

By assessing the performance, one can conclude that the system is non-linear in nature. To study such a system (3), (4) and to define optimal control over it, it is necessary to use the method of analytical construction of aggregated controllers.

$$\frac{dT_{ins}(t)}{dt}=M_1\cdot\left[M_2\cdot Q_h(t)+S_a(t)-M_3\right]-$$
$$-\left(\frac{\nu_v(t)}{M_4}+M_5\right)\left[T_{ins}(t)-T_{out}(t)\right], \quad (3)$$

$$\frac{d\varphi_{ins}(t)}{dt}=M_6\cdot Q_f(t)+M_7\cdot\left[E\left(S_a(t),\varphi_{ins}(t)\right)\right]-$$
$$-\frac{\nu_v(t)}{M_8}\left[\varphi_{ins}(t)-\varphi_{out}(t)\right], \quad (4)$$

where M_1–M_8 are the model's parameters that take into account design features of a greenhouse.

According to the method of analytical construction of aggregated controllers, it is necessary to define control laws u_i, which ensure optimal control over the modes of greenhouse operation. The chosen control u_1 is the value for air temperature inside a greenhouse $T_{ins}(t)$, the chosen control u_2 is the value for humidity of inside air in a greenhouse φ_{ins}.

In accordance with the method of analytical construction of aggregated controllers, control laws depend on:

$$u_1\left(Q_h, S_a, T_{ins}, T_{out}\right),$$
$$u_2\left(Q_f, \nu_v, \varphi_{out}, \varphi_{ins}\right). \quad (4)$$

Such laws are executed when the optimal values for temperature and humidity of inside air in a greenhouse are provided. To this end, it is necessary to ensure the power of the system that heats air in a greenhouse, the air exchange, which is provided for by a ventilation system. Important parameters also include the output of a fogging system and the solar radiation absorbed by a greenhouse. In addition, the temperature and humidity of air inside a greenhouse are dramatically affected by the temperature and humidity outside the greenhouse.

According to the method of analytical construction of aggregated controllers, we have defined managing actions shown in Fig. 1. To proceed with the study, we must consider invariant manifolds.

$$\psi_1\left(Q_h, S_a, T_{ins}, T_{out}\right)=0,$$
$$\psi_2\left(Q_f, \nu_v, \varphi_{out}, \varphi_{ins}\right)=0. \quad (5)$$

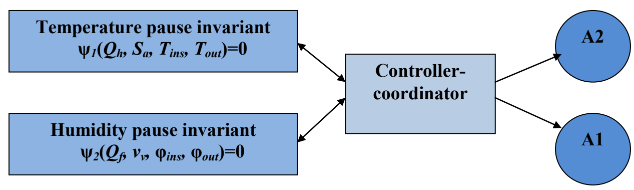

Fig. 1. Synergistic principle of hierarchy (A1 – temperature pause attractor; A2 – humidity pause attractor)

Parallel sequential consideration of invariant manifolds allows us to examine the invariants as attractors with pulling zones when applying control laws $u_1=(Q_h, S_a, T_{ins}, T_{out})$; $u_2=(Q_f, \nu_v, \varphi_{ins}, \varphi_{out})$.

The system floats across a phase space until intersecting the manifolds $\psi_1=0$, $\psi_2=0$. Since the output of a fogging system and the solar radiation absorbed by a greenhouse do not directly influence control u_1, u_2, it is necessary to provide this connection via ψ_i.

$$\psi_1=T_{ins}+\left(Q_h, S_a, T_{out}\right),$$

$$\psi_2=\varphi_{ins}+\left(Q_f, \nu_v, \varphi_{out}\right). \quad (6)$$

Considering dependences (5) and (6), we obtain:

$$T_{ins}+\left(Q_h, S_a, T_{out}\right)=0,$$
$$\varphi_{ins}+\left(Q_f, \nu_v, \varphi_{out}\right)=0. \quad (7)$$

To employ the method, it is necessary to apply (8):

$$T_{ins}\Psi_{ins}(\tau)+\Psi_{ins}(\tau)=0, \quad (8)$$

where τ is time, (s).

It follows from the model's equation and equation (8) that:

$$T_1\left[\frac{dT_{ins}}{dt}+\frac{d\nu}{dQ_h}\cdot\frac{dQ_h}{dt}+\frac{d\nu}{dS_a}\cdot\frac{dS_a}{dt}+\frac{d\nu}{dT_{out}}\cdot\frac{dT_{out}}{dt}\right]+$$
$$+T_{ins}+\nu+\left(Q_h,\,S_a,\,T_{out}\right)=0,$$

$$T_2\left[\frac{d\varphi_{ins}}{dt}+\frac{d\nu}{dQ_f}\cdot\frac{dQ_f}{dt}+\frac{d\nu}{d\nu_v}\cdot\frac{d\nu_v}{dt}+\frac{d\nu}{d\varphi_{out}}\cdot\frac{d\varphi_{out}}{dt}\right]+$$
$$+\varphi_{ins}+\nu+\left(Q_f,\,\nu_v,\,\varphi_{out}\right)=0, \qquad (9)$$

where ν is some dependence function of actual technological parameters. Control laws over technological pauses will equal:

$$u_1=\frac{T_{ins}+\nu}{\varphi_{ins}T_1}+\frac{\frac{Q_h}{M_2+Q_h}\cdot M_2\cdot\frac{M_3}{M_4+S_a\cdot M_4}}{\varphi_{ins}}+$$
$$+\frac{d\nu}{\nu S_a}\cdot\frac{\frac{\nu_v}{M_5+\nu_v}\cdot\frac{M_5}{M_4+T_{out}\cdot M_4}}{\varphi_{ins}}+\frac{d\nu}{\nu T_{out}},$$

$$u_2=\frac{\varphi_{ins}+\nu}{T_{ins}T_2}+\frac{\frac{Q_f}{M_6+Q_f}\cdot M_7\cdot\frac{M_6}{M_8+E}}{T_{ins}}+$$
$$+\frac{d\nu}{\nu E}\cdot\frac{\frac{\nu_v}{M_5+\nu_v}\cdot\frac{M_5}{M_4+\varphi_{ins}\cdot M_4}}{T_{ins}}+\frac{d\nu}{\nu\varphi_{ins}}, \qquad (10)$$

where T_1, T_2 are the synergistic controller's parameters.

A structural diagram of the considered control system for a greenhouse complex, executed in the software environment MATLAB Simulink 16, is shown in Fig. 2.

In a given scheme, functional unit fun_block1 simulates the resulting synergetic dynamic controller, it contains computation of macro-variable ψ_1, ψ_2, (6) and implements control law (10). Input signals to the unit is temperature and humidity. The output signal from the unit is control law u_1.

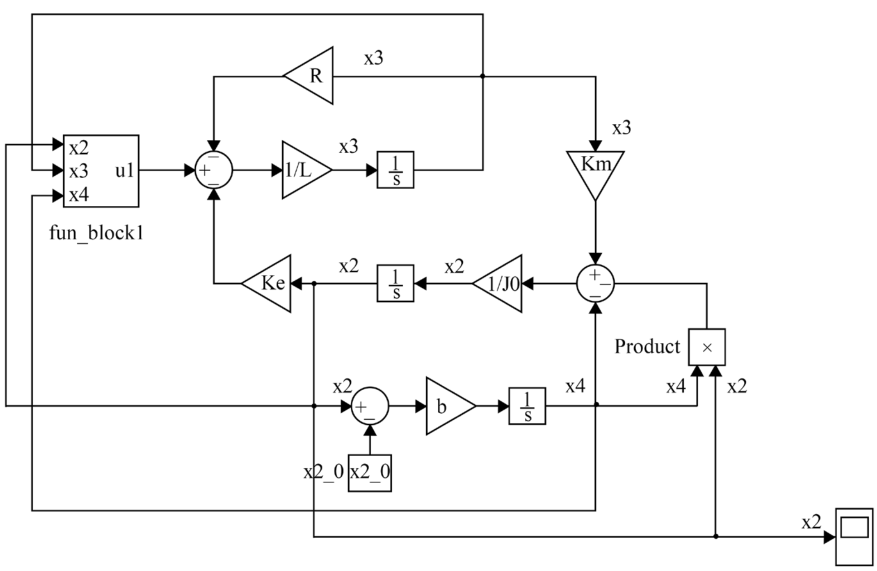

Fig. 2. Structural diagram of control system for a greenhouse complex

In order to achieve the set goal (for the derived control law), we shall synthesize a neural network controller by training it to functions implemented by unit fun_block1.

5. Synthesis of a neural network controller based on the synergetic control law

In a general case, solving the task set for the designed neural network controller reduces to synthesizing a multi-layer artificial neural network of direct propagation, trained to approximate the required function.

When building a neural network controller of this kind, it is important to determine:

– dimensionality of the neural network (the number of layers in the network and the number of neurons at each layer, required to ensure the required accuracy of functioning);

– the applied activation functions in neurons.

Determining the dimensionality of a neural network for solving a particular task very often depends on the experience of the developer. However, as noted by authors in [2], a network that consists of at least two layers and which has, in the hidden layer, an arbitrary number of neurons, could approximate almost any nonlinear function. This, in most cases, underlies the use of artificial neural networks to solve control tasks. Owing to their architecture, such networks make it possible to supplement an artificial neural network with *a priori* knowledge about the desired law of signal processing within the network.

Based on this, to solve the set problem, it is advisable to choose a double-layer artificial neural network of direct propagation. Because the chosen input signals to the network are ψ_1, ψ_2, the chosen output signal – control law $u1$, then the number of neurons in the input layer is 2 (the number of input components), in the output layer – 1 neuron. In this case, the number of neurons in the hidden layer is considered to equal 40. A given number is selected considering the provision of a reserve redundancy in the structure of the neural network.

We shall apply, as an activation function in neurons at the hidden and output layer, a sigmoidal activation function, which:

– satisfies the conditions for the input data range (0, 1);

– makes it possible to implement the full range of values for input signals;

– does not limit a solution that employs the neural network with discrete values.

In the process of learning, inside an artificial neural network, its own algorithm-solution is generated, according to which the information that enters the network is generalized. That is why, it is expedient to form, as a training sample, the sets of signals that most fully capture the entire range of possible input signals and corresponding solutions at the output. In this case, to produce an optimal solving algorithm, we shall train the neural network in the form not explicitly dependent on time.

6. Results of synthesis of the neural network controller for a greenhouse complex

Our research based on artificial neural networks for a greenhouse complex has made it possible to "teach" a neural network controller. At the next stage, it is necessary to calculate parameters for the units that will scale the input and output signals in order to ensure the proper functioning of the intelligent system.

The accepted parameters for a control system whose structure employs a neural network controller take the form shown in Fig. 3.

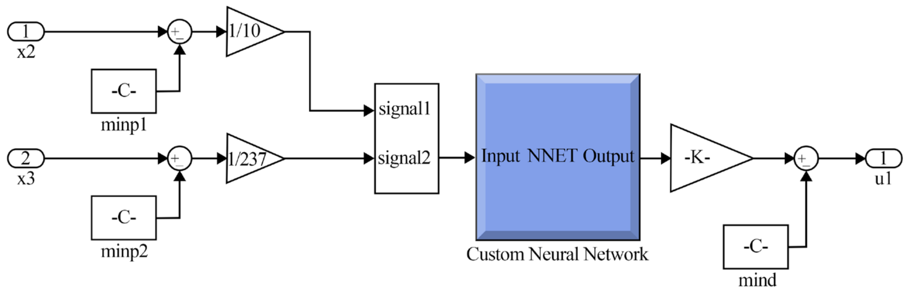

Fig. 3. Structure of the neural network controller for a greenhouse complex

Having synthesized a neural network controller in this fashion and by placing it inside a closed control system, we shall evaluate its functioning. To do this, we shall assign the above-presented parameters for the control system and simulate system operation at different values for temperature and humidity at a greenhouse complex. Fig. 4 shows simulation charts for a temperature inside a greenhouse of 24 °C.

Fig. 5 shows simulation charts of air humidity inside a greenhouse (humidity value=60 %).

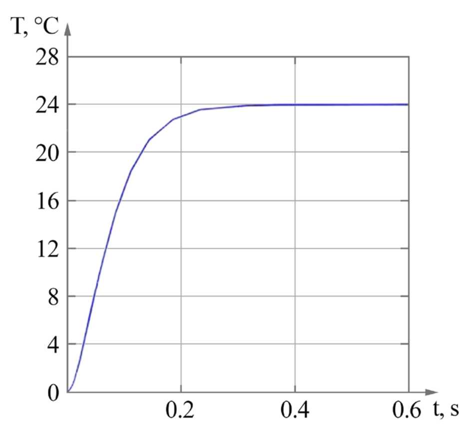

Fig. 4. Charts of temperature change inside a greenhouse, at T=24 °C

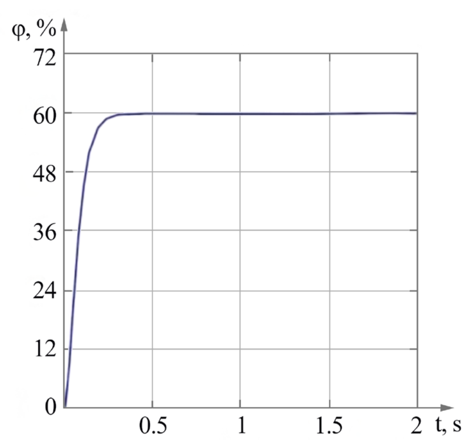

Fig. 5. Charts of change in humidity inside a greenhouse, at φ=60 %

Next, we shall simulate, by employing the Simulink programming tools, external disturbing effects on a neural network system for two cases:

1) random disturbance that generates a signal that is filled according to the Gaussian distribution;

2) the disturbance of harmonic character.

Simulation results for random disturbances are shown in Fig. 6.

Simulation results for harmonic disturbances are shown in Fig. 7.

In general, the simulation results show (Fig. 6, 7) that a neural network controller, synthesized based on the synergetic dynamic controller (8), demonstrates, compared with conventional approaches, better quality indicators for transients. As well as over a wide range of changes in parameters: temperature, air humidity in a greenhouse, greenhouse air heating system capacity, the output of a fogging system, solar radiation absorbed by a greenhouse, heat of vaporization, air exchange that is enabled by a ventilation system; it possesses capability to adapt to parametric and external disturbances.

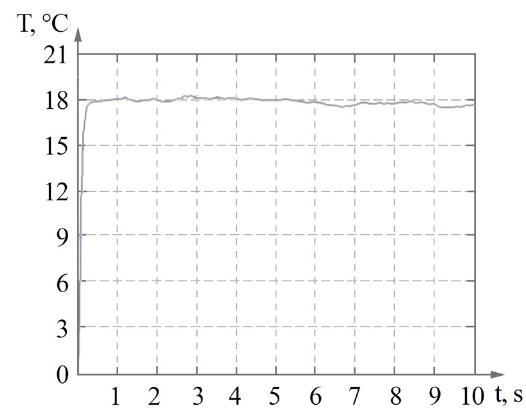

Fig. 6. Chart of change in temperature when a system is exposed to random disturbances

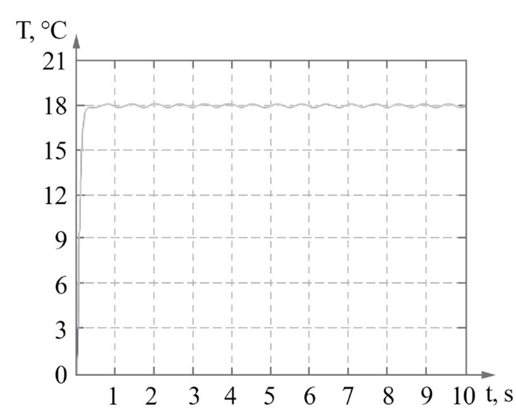

Fig. 7. Chart of change in temperature when a system is exposed to harmonic disturbances

7. Discussion of results of the synergistic synthesis of controller

Practical value of the research results obtained when applying a synergistic approach to artificial systems is in that such systems are characterized by ideology of unification in the processes of targeted self-organization and control. According to the method of analytical construction of aggregated controllers, we have defined managing actions for a greenhouse complex, shown in Fig. 1. In addition, the considered invariant manifolds have made it possible to construct the laws controlling the temperature and air humidity in a greenhouse (10), which ensure the optimal management of the greenhouse operating modes. Owing to this, there is the possibility to generate predictive information that would allow the design of a variety of systems.

The use of artificial neural networks for a greenhouse complex (namely, their features – learning on the experimental sample and parallel information processing) provides high performance (Fig. 6, 7). The performed synthesis of a neural network controller for a greenhouse complex produces its own solving algorithm, according to which the information about a value for temperature and humidity inside a greenhouse that enters the network is generalized. We have formed the sets of signals (9) to use as a training sample, which most fully capture the entire range of possible input signals and corresponding solutions at the output. Construction of the optimal solving algorithm to train a neural network is given in the form not explicitly dependent on time. It should also be noted that our study makes it possible to simultaneously monitor processes that occur at an actual facility. This becomes possible through the distributed processes of internal functioning.

Having synthesized the neural network controller and by placing it inside a closed system of management, we estimated its functioning. The assigned parameters for the control system (10) and simulation results at different values for temperature and humidity at a greenhouse complex are shown in Fig. 4–7.

Thus, the integrated use of the synergistic approach (6) and neural network structures (10) has made it possible to synthesize an intelligent control system for a greenhouse complex, whose feature is parallel computation of patterns in functioning and accounting of the principles of inner self-organization.

The disadvantage of the current research is an insufficiently high degree of examining the artificial neural network redundancy, which ensures the safety of functioning at disruption of a connection or at loss of controlling influences.

In the future, we plan to undertake a research into a greenhouse complex using the synergistic approach and artificial neural networks for the entire set of technological parameters and material flows.

7. Conclusions

1. We have constructed laws to control the air temperature and humidity in a greenhouse according to the analytical construction of aggregated controllers that ensure optimal control over the greenhouse operation modes. The proposed synergistic controller for a greenhouse complex possesses a kind of "intelligence" and so successfully adapts to non-controlling disturbances (disturbing effects on a neural network system that form a Gaussian-distributed signal and the disturbances that are harmonic in character) that act on the system.

2. To derive the laws to control temperature and humidity inside a greenhouse, we have synthesized a neural network controller and trained it on functions that are implemented by unit fun_block1. This enabled the development of effective systems of synergetic control that ensure maximal utilization of own resources of the controlled object owing to the phenomena of self-organization.

3. The synergistic synthesis of controller for a greenhouse complex has been performed. The simulation results showed that the neural network controller, synthesized on the basis of a synergetic dynamic controller, demonstrates, when compared to conventional approaches, better quality indicators of transient processes and adaptation to parametric and external disturbances.

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