INTELLIGENT EFFECTIVE MANAGEMENT SYSTEM OF BIOTECHNICAL OBJECTS BASED ON NATURAL DISTURBANCES PREDICTION

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Abstract

This article analyses Biotechnical objects as complex processes and external disturbances on them; promising areas of management systems of biotechnical objects development are identified; methodological bases for specialized algorithmic-mathematical software construction based on the methods of game theory and statistical solutions, neural networks (including genetic algorithm), filtering the noise components of information signals are synthesized and tested; variety of architectures of intelligent effective management systems of biotechnical objects are developed and tested.

Key words: biotechnical object, control system, game theory, statistical decisions, neural network, genetic algorithm, Hilbert Huang transforms.

Introduction

In modern conditions of unbridled growth in energy prices and inevitable approach of the global food crisis agricultural production as well as any other production should be effective. As the data (Мельник, 2006; Ярошенко, 2004; Іваненко, 2011), the effectiveness of the industrial production of agricultural products is determined by the whole system of interrelated factors: the cost of primary production per unit of production (technological facilities, equipment, biological objects (bioobjects), human labor, etc.), productivity of bioobject (poultry, domestic animals, plants, mushrooms, etc.), selling price, cost, consumption of accompanying resources (feed, water, premixes, pharmaceuticals, substrates, fertilizers, carbon dioxide, protection, etc.), costs of non-renewable energy sources (electricity, fuels and lubricants, etc.), quality, cost and consumption way of these resources, quality of the products.

Experts-economists (Мельник, 2006; Ярошенко, 2004; Іваненко 2011) indicate these two key opportunities to improve the efficiency of production at each plant of the agricultural sector: first, the productivity growth of bioobject, reducing the cost of accompanying resources and improve their balance, as well as the economical use of non-renewable energy resources due to the introduction of new technologies on the basis of innovation, and secondly, the state with the interests of the economy, is obliged to create conditions through economic instruments that allow enterprises to use innovation in production.

Decision-making in managing the production of agroproducts using criteria considered for improving efficiency is a difficult task (Лисенко et al. 2007). State of a bioobject is the result not only of deterministic actions but also depends on the random disturbances caused by weather conditions, which cannot be predicted and accurately defined (Lysenko et al. 2011). Therefore, the management decisions should be made under uncertainty. Efficiency index in this case can be represented as follows:

$$I = \int_{t_n}^{t_k} f(x,y,u)dt, \quad (1)$$

where $f(x,y,u)$ – function depending on the bioobject state (x), uncertain conditions (y) and the decision (u) to manage the process for all the time from the beginning of bioobject housing (t_n) till completion the process (t_k).

Then the problem of optimal solution determination for the process control is formulated as follows: for a given state x with the unknowns y to find control actions u, which would, if possible, drive up to the maximum efficiency index I of the process.

When you consider all of the above factors of quality in the management of the production process, the task of management should be viewed as multi-criteria, which greatly complicates the solution. Under such circumstances, the most appropriate is the only criterion I, which is to maximize profit – from the price difference between C_p – price of received production and cost C_b – basic cost of its production, given the uncertain state of the object:

$$I = \sum_{i=1}^{k} \left(C_{pi} - C_{bi} \right) \Rightarrow \max \, , \tag{2}$$

where k – the number of system states during the production cycle.

In this case the constraints on the probability of bioobject death or certain percentage of losses of its representatives must be taken into account.

The cost of basic production and accompanying resources can be accurately calculated, taking into account their long-term use, but the energy costs that depend on natural disturbances acting on the technological object can be as predictable as possible to predict natural disturbances.

So, the task of choosing control actions is largely dependent on the ability of control system to predict natural disturbance and dynamics of the bioobject quality indexes (Лисенко et al. 2007).

Natural disturbances affecting the state of agricultural bioobjects are air temperature, relative humidity and solar radiation (Лисенко et al. 2007). Determining influence on almost all production processes provides natural air temperature disturbances.

Materials and Methods

Our analysis of international experience in the field of automation of management processes in agriculture showed that all of the existing control systems do not take into account possible future changes in the disturbances, in particular air temperature, on the technological object during the entire period of bioobject housing (growing), as well as the dynamics of bioobject states and perform exclusively stabilization mode for technological parameters, given the instantaneous values of the disturbances that is not always effective (Щербатюк, 2012).

Since these natural disturbances are non-stationary stochastic processes, predicting their parameters with proper for the production needs accuracy using classical control systems is virtually impossible (Лисенко et al. 2009). However, there are several methods for modelling natural disturbances (Тихомирова, 2003) using interpolation formulas, by extrapolation of random processes and their representation in the form of autoregressive processes of the second degree, or a moving average, etc. However, these methods do not provide the predicted values for a set of external disturbances, the characteristics of which are essentially different. According to the results of this modelling it can be determined only statistical characteristics of random variations and parameters of deterministic components of the disturbances. But having these data it is impossible to reproduce the possible implementations of the disturbances (Тихомирова, 2003) and use them to select the effective control actions while production process in use.

The developed mathematical models, software and hardware, intelligent control system for biotech objects (Лисенко and Головінський, 2005; Лисенко et al. 2009; Лисенко et al. 2010; Лисенко et al. 2010; Лисенко et al. 2011) based on the techniques of modern control theory, mathematical statistics, stochastic processes, game theory and statistical decisions, neural networks, genetic algorithm, filtering, means of new information technologies have demonstrated their effectiveness in laboratory conditions and field tests (Лисенко et al. 2010).

Results

On the basis of fundamental research we have created an intelligent control system (Лисенко et al. 2009; Лисенко et al. 2010; Щербатюк 2012), where the algorithm using criterion (2) was implemented. There I is the expectation $\bar{I}$ of profit from the produce and process control is performed depending on the physical condition of the bioobject and considering possible natural air temperature disturbances. This is two-level adaptive system, the functional structure of which is shown in Fig. 1.

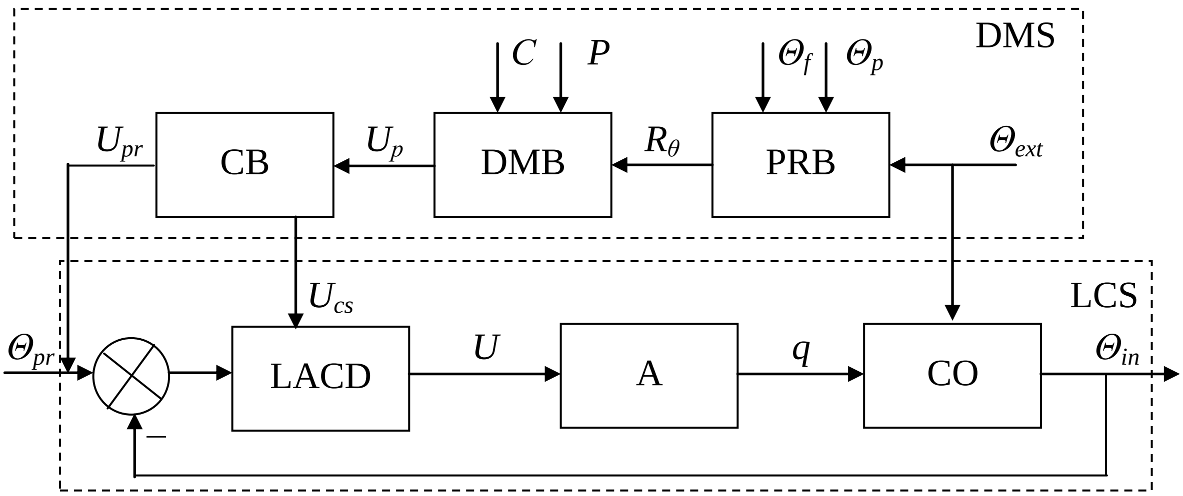

Figure 1. Functional structure of the control system

DMS – decision-making subsystem, PRB – pattern recognition block, DMB – decision-making block, CB – control block, LCS – local control system, LACD – local automatic control device, A - actuators, CO – control object, Θ_{ext} – external air temperature, Θ_p – air temperature patterns, Θ_f – weather forecast, R_θ – recognized pattern, C – cost of resources, P – product price, U_p – control strategy, U_{pr} – preselected actions, Θ_{pr} – preselected internal air temperature value, U_{cs} – control strategy actions, U – control signals for the actuators, q – physical influences on CO, Θ_{in} – internal air temperature.

Intellectual components of the system are PRB and DMB, the main purpose of which is to predict the future external disturbances, the bioobject states and to develop optimal control strategies according to the chosen effectiveness criterion. The operation principles of these units are described below.

Based on the statistical analysis of long-term changes in weather conditions for different regions of Ukraine the classification of natural disturbances and their mathematical models were developed. As it turned out, the year realizations of the changing weather conditions are non-stationary random process and determination of its statistical characteristics is extremely complex stochastic task solution of which is virtually impossible. However, the analysis of changes in individual sections of these time series has shown that they can be predictable, as they are implementations of stationary or quasi-stationary random processes. The mathematical model of such sections is additive:

$$\theta_i = u_i + W_i + S_i + \varepsilon_i \, , \tag{3}$$

where u_i – trend; W_i – cycles; S_i – seasonal component; ε_i – random component.

On the basis of the reference method K-means cluster analysis of the temperature sections is performed. It is allowed to make their classification and create a system of the patterns – natural air temperature disturbances. The system includes five classes depending on the values of certain probabilistic and deterministic characteristics of the time series.

Thanks to the Bacon’s serial approach of meteorological event sustainability it is proved suitability to predict the natural air temperature changes up to 4 days.

By the application of statistical techniques it is performed the study of bioobject state changes (for hens) depending on the external disturbances and control actions that allowed to develop the mathematical models of the dynamics of bioobject quality indexes (Лисенко et al. 2011).

As in the process it is necessary to make management decisions under uncertainty, for biotechnical systems we have taken the approach of statistical games (games with nature) based on the analysis of the payoff matrix with a compromise Hurwitz criterion. In this case, the players are on the one hand the control system by selecting and performing some complex control actions (control strategies) seeks to maximize profits in the production process, and on the other hand – nature with its random air temperature changes (strategies of nature).

Thus, the main purpose of the PRB to determine the strategies of nature, i.e. recognition and reproduction of the future external air temperature fluctuations. To do this, we have developed a three-step pattern recognition algorithm which is set up in successive refinement of deterministic and statistical characteristics of the disturbance changes outside the control object, using information on previous weather conditions, the parameters of which are fixed by the control system, and the forecast of Ukrainian Hydrometeorological Center. The technique is based on a comparison of the object closeness degree (air temperature change sections) with all the patterns. Acquisition of the air temperature fluctuation implementations occurs according to the shaping filter method and using the distribution functions. Long-term tests of the pattern recognition algorithm have shown its effectiveness since the error values of pattern parameters and the actual future implementation do not exceed 0.8 ˚C.

Due to the use of the developed intelligent system in the poultry plant compared to traditional microclimate stabilization control systems the bioobject productivity remains virtually unchanged, energy costs reduce, particularly electricity – by 20.82 % , feed – by 0.5 %.

It was shown (Лисенко et al. 2010) that the control system can be used not only in Ukraine, but also in other areas with different climatic conditions and for other types of bioobjects.

Along with the above approach to predict natural air temperature disturbances, we carried out fundamental research (Лисенко et al. 2011; Лисенко et al. 2011; Лисенко et al. 2012) and developed a method of pattern recognition and reproduction of future air temperature fluctuations on the basis of probabilistic neural networks (PNN).

It was proposed to transform the control system architecture (Fig. 1) into the structure shown in Fig. 2, where the recognized pattern (R_{Θ}) and probability of air temperature pattern appearance (p) from PRB and neural network pattern state estimate block (NNPSEB) respectively, are transferred to DMB.

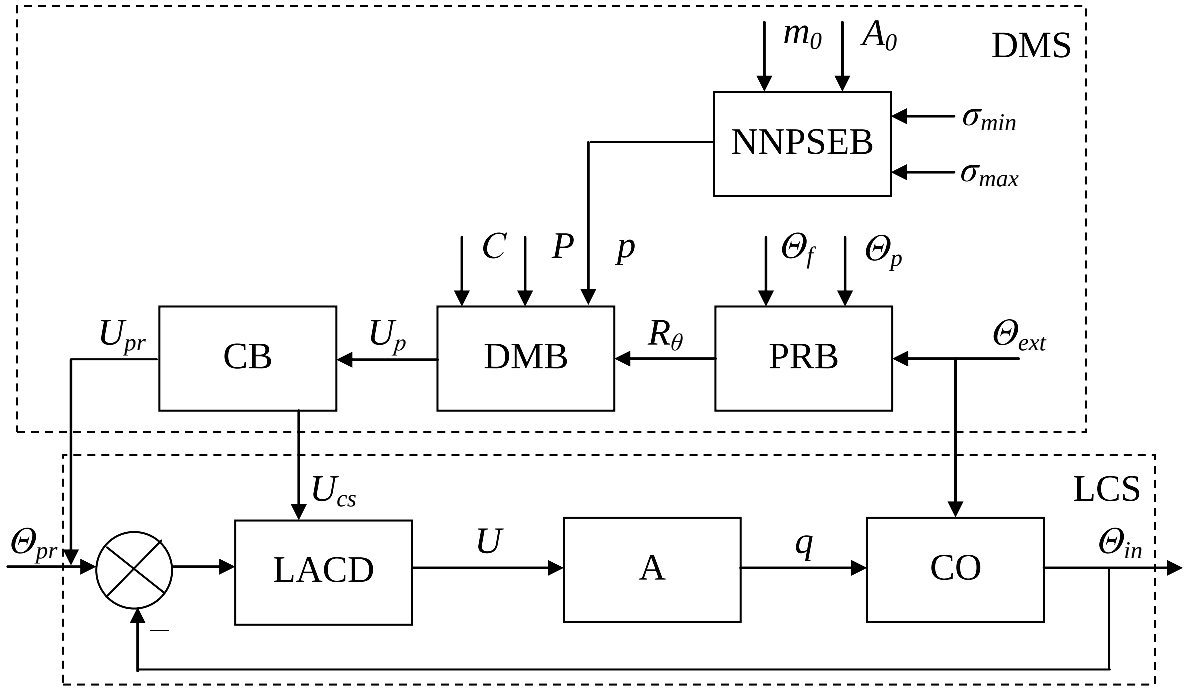

Figure 2. Functional structure of the control system with neural network pattern state estimate block (NNPSEB)

σ_{min} – minimal mean square deviation of air temperature section, σ_{max} – maximal mean square deviation of air temperature section, m_0 – mathematical expectation of air temperature section, A_0 – amplitude of air temperature section, p – probability of air temperature pattern appearance.

Thus, for the long-term statistics of natural air temperature disturbances, which was used in the above classification method, it was formed 132 patterns with corresponding numerical values of the input parameters (Лисенко et al. 2011; Лисенко et al. 2011). In solving classification problems the network outputs are interpreted as estimates of the probability whether an element belongs to some class. The network actually learns to evaluate the probability density function (Fig. 3).

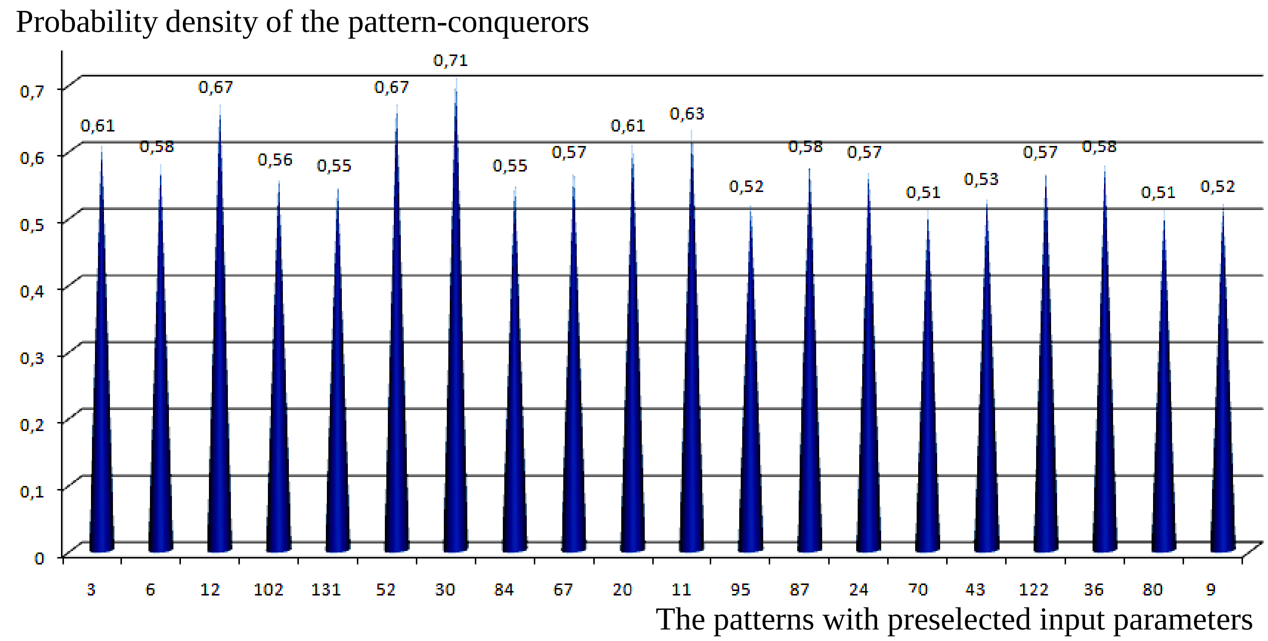

Figure 3. Probability density of the pattern-conquerors in the study of classification quality by PNN

In the synthesis of PNN-classifier thermal images as input variables we used the mathematical expectation of air temperature section (m_0), the amplitude of air temperature fluctuations (A_0), the minimal mean square deviation (σ_{min}) and the maximal mean square deviation of air temperature section (σ_{max}).

The use of neural network approach has allowed more accurately determine the onset and time of the pattern change, which has a significant influence on the production process management.

In the case of solar radiation (Лисенко et al. 2012), as one of the most important types of disturbances for plant bioobjects, it is found experimentally that such a time series is nonlinear and non-stationary without obviously marked deterministic components. Therefore, it was introduced the neural network time series prediction block (NNTSPB) into DMS. In this architecture, the control system (Fig. 4) the predicted value of natural disturbance (Z_p) from NNTSPB is transferred to DMB. The database of DMB includes for each prediction possible control actions and quality indexes for each action as to the production results, material and energy costs in physical units.

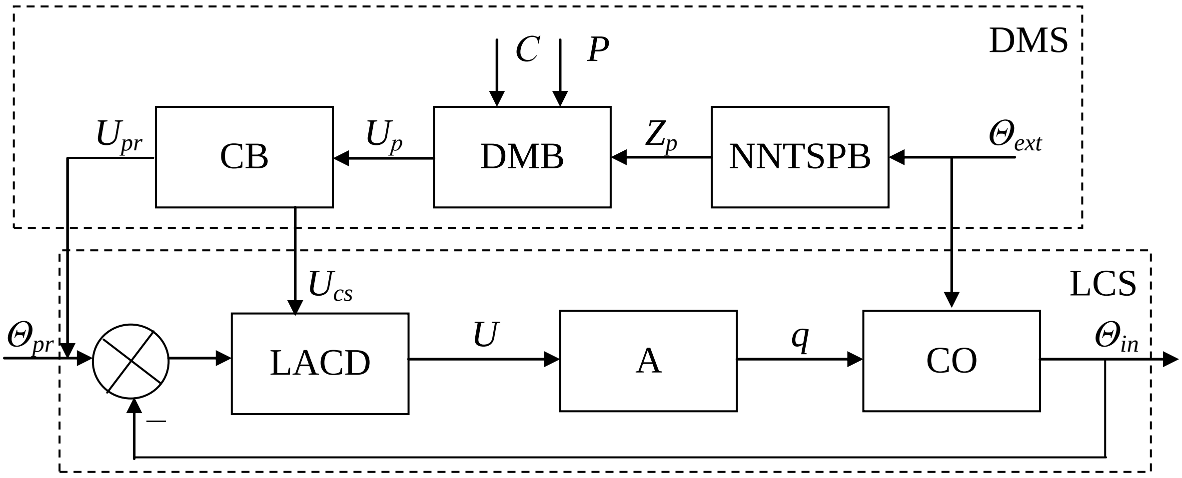

Figure 4. Functional structure of the control system with neural network time series prediction block (NNTSPB)

Z_p – predicted value of natural disturbance.

As a basic it was used neural networks with logistic activation functions. The depth of the neural network prediction for agricultural bioobjects should be no more than 15-20 hours.

Furthermore, NNTSPB, to reduce noise and improve prediction quality, should include the block of noise filtering of information signals on the basis of the Hilbert Huang transform and neural network adaptation block (optimizing the values of weighting coefficients) using genetic algorithm. It allows to improve on 4.8-9.3 % prediction quality for the intensity of solar radiation (Fig. 5), with a preliminary filtering of the input signal (noise component to 16 %).

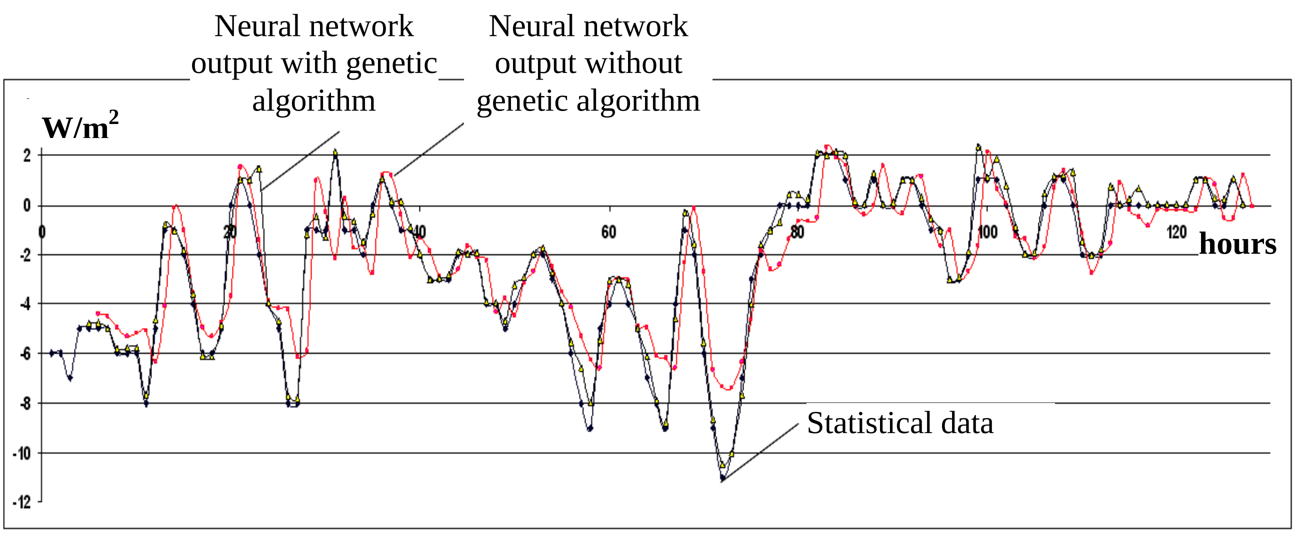

Figure 5. Diagrams of time series training prediction of solar radiation by means of neural networks (with optimization by genetic algorithm and the method of “rapid” descent) after filtering the signal by Hilbert Huang transform.

According to the analysis of the above two methods for prediction disturbances on biotechnical objects: the pattern recognition and reproduction algorithm (PRRA) and based on the methods of the theory of stochastic processes, on the one hand, and the approach using neural networks (NN), on the other hand, we came to the following conclusions.

In contrast to PRRA NN prediction does not require statistical data on air temperature changes in the past, the development of their patterns, that is working under conditions of uncertainty. However, it requires a long time for training, and prediction reliability is sensitive to the quality of the input representation, and it is impossible to enter a priori (expert) information to speed up the learning network.

As for the performance of the prediction algorithms, the use of PRRA allows to change the algorithm to adjust it with a view to improving the PRB functioning, while NN prediction is complex for analysis of the “taught” network structure.

Prediction depth of these methods also differs: NN is able to more accurately estimate future fluctuations in air temperature (Fig. 6a), but for a period of 1 day, whereas PRRA allows to develop forecast for a 4-day period and works more effectively in the quasi-stationary air temperature sections (Fig. 6b), but requires clarification during the time of the algorithm performance.

Prediction of the stationary sections without deterministic components using PRRA shows great precision: standard error – 3.5 % vs. 4.9 % using NN.

In the presence of a periodic component in the air temperature fluctuations NN has demonstrated better quality: its mean-square error – 4.8% vs. 5.8% using PRRA.

From the above it follows that the approach to the integrated use of the advantages and removal disadvantages of these mathematical apparatus, which were the basis for the intelligent control system for biotech objects is scientifically sound. It allows to not only use the a priori information but to acquire new knowledge in the process effectively adapting to the disturbing influences.

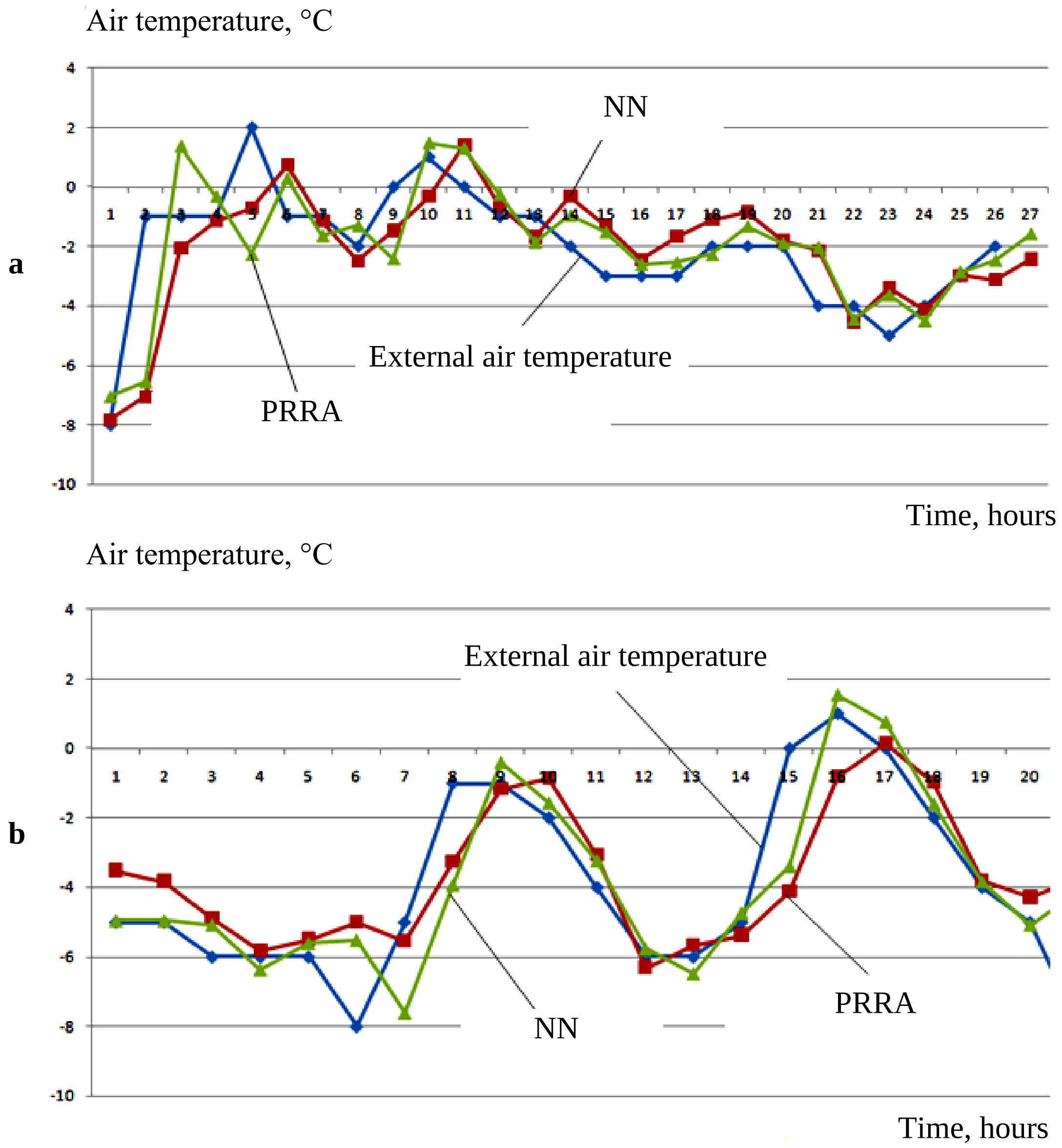

Figure 6. Diagrams of prediction quality comparison PRRA and NN

Conclusions

The paper proposed a new solution to improve the efficiency of the industrial production of agricultural products through the development and implementation of the intelligent control system of biotech objects due to the use of the techniques of modern control theory, mathematical statistics, stochastic processes, game theory and statistical decisions, neural networks, genetic algorithm, filtering, means of modern information technology. It is proved that in contrast to existing systems for today the most appropriate efficiency criterion for the process control system of agricultural production is to maximize profits, taking into account the dynamics of the bioobject physical condition and possible natural disturbances on the object based on the integrated use of neural networks and theory of stochastic processes methods to predict disturbances. Due to the use of the developed system (for example, the process of housing laying hens), compared with the traditional system of microclimate stabilization the bioobject productivity remains virtually unchanged, energy costs reduce, particularly electricity – by 20.82 %, feed – by 0.5 %. It is demonstrated that the developed control system can be used not only in Ukraine, but also in other areas with different climatic conditions and for other bioobjects.

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