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Energy-efficient modes for management of biotechnical objects based on natural disturbances prediction

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Abstract: *Energy-efficient modes for management of biotechnical objects based on natural disturbances prediction.* Nowadays overwhelming majority of biotechnical objects in agriculture, such as poultry houses, greenhouses etc., function under the mode of stabilization of technological parameters (air temperature, humidity etc.). This approach leads to excess consumption of energy resources (electrical energy, natural gas). Intelligent control based on using different strategies (not only stabilization), prediction and consideration of natural disturbances on biotechnical objects, physiological features of biological objects (poultry, plants etc.) allows to reduce energy consumption. The paper presents specific knowledge concerning promising areas of control systems of biotechnical objects, 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.

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

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 [Yaroshenko 2004, Melnyk 2006, Ivanenko 2011a, Ivanenko 2011b], 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 resources 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 [Yaroshenko 2004, Melnyk 2006, Ivanenko 2011a, Ivanenko 2011b] indicate these two key opportunities to improve the efficiency of production at each plant of the agricultural sector:

- 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;
- state with the interests of its economy, is obliged to create conditions through economic instruments that allow enterprises to use innovation in production.

Nowadays overwhelming majority of biotechnical objects in agriculture, such as poultry houses, greenhouses etc., function under the mode of stabilization of technological parameters (air temperature, humidity etc.). This approach leads to excess consumption of energy resources (electrical energy, natural gas).

Intelligent control based on using different strategies (not only stabilization), prediction and consideration of natural disturbances on biotechnical objects, physiological features of biological objects (poultry, plants etc.) allows to reduce energy consumption.

MATERIAL AND METHODS

Decision-making in managing the production of agroproducts using criteria considered for improving efficiency is a difficult task [Lysenko 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 can not be predicted and accurately defined [Lysenko et al. 2011a]. Therefore, the management decisions should be made under uncertainty. Criterion in this case can be represented as follows:

$$I = \int_{t_n}^{t_k} f(x, y, u)\mathrm{d}t \qquad (1)$$

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

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 ($I_{\max}$) 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:

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

where: k – 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 [Lysenko et al. 2007].

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

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 [Shcherbatyuk 2012].

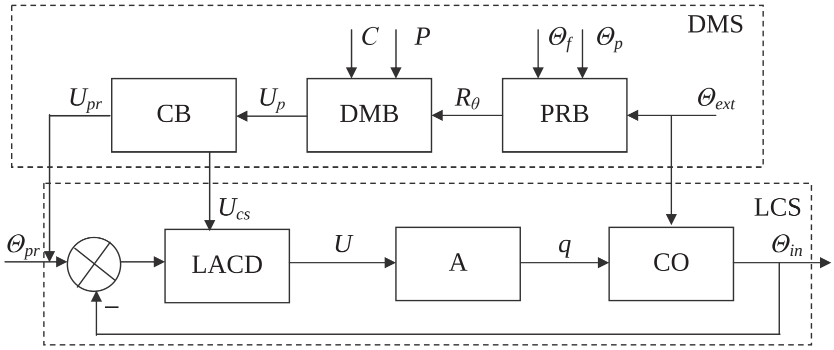
Since these natural disturbances are non-stationary stochastic processes, predicting their parameters with proper for the production needs accuracy using classical control systems is virtually impossible [Lysenko et al. 2009a]. However, there are several methods for modeling natural disturbances [Tikhomirova 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 modeling, 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 [Tikhomirova 2003] and use them to select the effective control actions while production process in use.

The developed mathematical models, software and hardware, intelligent control modes for biotech objects [Lysenko and Golovinskyi 2005, Lysenko et al. 2009b, Lysenko et al. 2010a, Lysenko et al. 2010b, Lysenko et al. 2011b] are 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. They have demonstrated their effectiveness in laboratory conditions and field tests [Lysenko et al. 2010a].

RESULTS

On the basis of fundamental research we have created an intelligent control system [Lysenko et al. 2009b, Lysenko et al. 2010a, Shcherbatyuk 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 Figure 1.

Intelligent components of the system are PRB and DMB, the main purpose of which is to predict the future external



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.

FIGURE 1. Functional structure of the control system

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 – component of 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 [Lysenko et al. 2011a].

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.

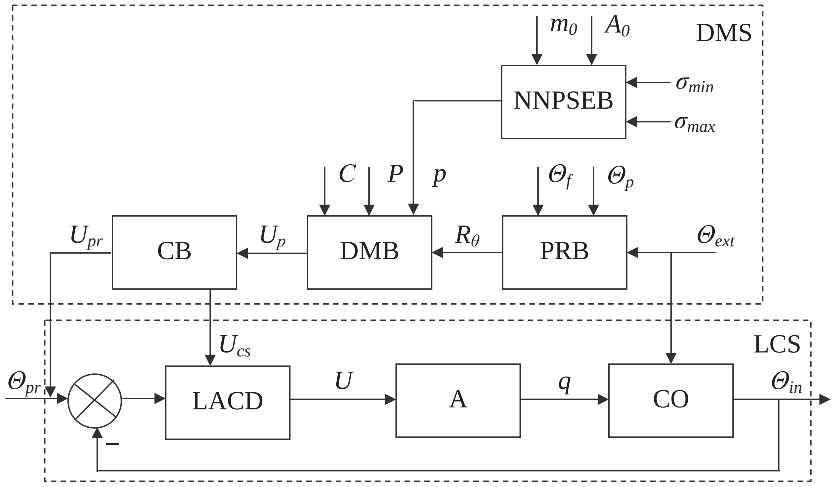
Due to the use of the developed intelligent system in the poultry plant compared to traditional microclimate stabilization control systems the bioobject productivity remains virtually unchanged, energy costs reduce, particularly electricity – by 20.82%, feed – by 0.5%.

It was shown [Lysenko et al. 2010b] 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 [Lysenko et al. 2010c, Lysenko et al. 2011b, Lysenko 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 Figure 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.

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 [Lysenko et al. 2010c, Lysenko et al. 2011b]. 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.



$\sigma_{\min}$ – minimal mean square deviation of air temperature section, $\sigma_{\max}$ – 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.

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

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.

From the above it follows that the approach to the integrated use 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.

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. There were used 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.

REFERENCES

MELNYK B. 2006: Economy, organization and strategy for development of industrial poultry farming in Ukraine [in Ukrainian]. Poligraphinko, Kyiv.

YAROSHENKO F. 2004: Poultry farming of Ukraine: state, problems and perspectives of development [in Ukrainian]. Agricultural Science, Kyiv.

IVANENKO V. 2011a: Research of cost effectiveness and energy dependence of leading greenhouse complexes [in Ukrainian]. In: Forming of Market Economy. Kyiv National Economic University named after Vadym Hetman. Part 2: 97–107.

IVANENKO V. 2011b: Effectiveness of implementing of energy saving technologies into greenhouse production [in Ukrainian]. In: Productivity of agricultural production. Ukrainian Research Institute of Productivity of Agricultural Complex. Vol. 18: 101–107.

LYSENKO V., GOLOVINSKIY B., GOLUB B., RUDENSKYI A. 2007: Techniques and means of modern automated control [in Ukrainian]. National Agricultural University of Ukraine, Kyiv.

LYSENKO V., GOLOVINSKIY B., RESHETYUK V., GOLUB B., SHCHERBATYUK V. 2011a: Dynamics of quality indexes of laying hens keeping process due to fluctuations of temperature disturbances in an industrial poultry house [in Ukrainian]. Annals of Warsaw University of Life Sciences – SGGW 57: 79–92.

SHCHERBATYUK V. 2012: Automatic egg production control system on the basis of the disturbance prediction [in Ukrainian]. Dissertation, Kyiv (msr).

LYSENKO V., GOLOVINSKYI B., RUDENSKYI A. 2009a: Modelling of temperature disturbances under biological objects housing [in Ukrainian]. Bulletin of Agricultural Science, National Academy of Agricultural Sciences of Ukraine 6: 49–55.

TIKHOMIROVA N. 2003: Intelligent information systems in economy [in Russian]. Ekzamen, Moscow.

LYSENKO V., GOLOVINSKYI B. 2005: Effectiveness estimation technique of control systems for housing conditions of biological objects for industrial production of agricultural products [in Ukrainian]. Agricultural Science and Education, National Agricultural University of Ukraine 6 (3–4): 127–133.

LYSENKO V., GOLOVINSKIY B., SHCHERBATYUK V. 2009b: Control system for biological objects housing process in agriculture [in Ukrainian]. Patent 44637 of Ukraine G05B 13/00.

LYSENKO V., GOLOVINSKYI B., RESHETYUK V., SHTEPA V., RUDENSKYI A., GOLUB B., LAVINSKYI D., PUKHA V., SHCHERBATIUK V. 2010a: Technical means of computer-integrated control system for effective energy resources management in poultry farm [in Ukrainian]. Bioresources and Nature Management, National University of Life and Environmental Sciences of Ukraine, 2 (3–4): 111–118.

LYSENKO V., GOLOVINSKIY B., RESHETYUK V., GOLUB B., RUDENSKYI A., PUKHA V., SHCHERBATYUK V. 2010b: Guidance for design of energy saving systems in industrial production of agricultural products [in Ukrainian]. National University of Life and Environmental Sciences of Ukraine, Kyiv.

LYSENKO V., SHTEPA V., DUDNYK A. 2011b: Stochastic (Bayes) neuronet of temperature patterns classification [in Ukrainian]. Bulletin of Agricultural Science, National Academy of Agricultural Sciences of Ukraine 4: 53–56.

LYSENKO V., ZAIETS N., SHTEPA V., DUDNYK A. 2010c: Neuronet prediction of environmental air temperature time series [in Ukrainian]. Bioresources and Nature Management, National University of Life and Environmental Sciences of Ukraine 3 (3–4), 102–108.

LYSENKO V., SHTEPA V., DUDNYK A. 2012: Hilbert Huang transform and filtration of solar radiation time series [in Ukrainian]. Bulletin of Kharkiv National Technical University of Agriculture, Ukraine 130: 55–58.

Streszczenie: *Metody efektywnego energetycznie zarządzania obiektami biotechnicznymi na podstawie przewidywanych zakłóceń naturalnych.* Aktualnie większość biotechnicznych obiektów w rolnictwie, takich jak kurniki, szklarnie i inne, funkcjonują z uwzględnieniem metody stabilizacji technologicznych parametrów środowiska (temperatura powietrza, wilgotność powietrza itp.). Takie podejście prowadzi do nadmiernego zużycia źródeł energii (energii elektrycznej, gazu). Inteligentna kontrola i sterowanie bazujące na wykorzystaniu różnych strategii (nie tylko strategii stabilizacji), przewidywaniu i uwzględnianiu naturalnych zakłóceń w obiektach biotechnicznych, a także fizjologicznych cech obiektów biologicznych (drób, materiał roślinny itp.) pozwalają na zmniejszenie zużycia energii. W artykule przedstawiono szczegółową wiedzę dotyczącą obszarów włączenia systemów kontroli obiektów biotechnicznych, metodologicznie bazujących na specjalistycznym oprogramowaniu algorytmiczno-matematycznym z uwzględnieniem metod teorii gier i statystycznych rozwiązań, sieci neuronowych (uwzględniając algorytm genetyczny) filtrujących elementy składowe sygnałów informacyjnych.

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