INT. J. BIOAUTOMATION, 2020, **24**(1), 51-64 doi: 10.7546/ijba.2020.24.1.000612

Rationale for the Structural Organization of a Computerized Monitoring and Control System for Greenhouse Microclimate Using the Scale Transformation Method

Ivan S. Laktionov[1*], Oleksandr V. Vovna[1], Volodymyr I. Bondarenko[2], Anatolii A. Zori[1], Vladyslav A. Lebediev[1]

[1]*Department of Electronic Engineering*
State Higher Educational Establishment "Donetsk National Technical University"
of the Ministry of Education and Science of Ukraine
UA85300, Shybankova Sq., 2, Pokrovsk, Ukraine
E-mails: ivan.laktionov@donntu.edu.ua, oleksandr.vovna@donntu.edu.ua,
anatolii.zori@donntu.edu.ua, vladyslav.lebediev@donntu.edu.ua

[2]*Department of General Technical Disciplines,*
Safety of Vital Activity and Automotive Engineering
State Higher Educational Establishment "Donbas State Pedagogical University"
UA84116, Henerala Batiuka Str., 19, Sloviansk, Ukraine
E-mail: nv1287@ukr.net

[*]*Corresponding author*

Received: September 04, 2018 **Accepted: February 19, 2019**

Published: March 31, 2020

Abstract: *Industrial greenhouses are complex engineering structures that should provide control and operational management over microclimate parameters that affect the efficiency of evapotranspiration and photosynthesis processes, there by determining the rates of growth, volume and quality of vegetable production. The proposed method of physical modelling of the dynamics of microclimate parameters, in contrast to existing ones, takes into account the complex effect of the regulated list of controlled quantities on photosynthetic efficiency of greenhouse crops. An improved structural and algorithmic organization of a computerized information and measurement system for monitoring and control over industrial greenhouse microclimate has been synthesized, which takes into account the current trends in the development of infocommunication, sensory and microprocessor technologies. A laboratory prototype of an industrial automated greenhouse has been created, which takes into account the conditions for geometric, kinematic and dynamic similarity to real greenhouses. Promising areas of further study of the proposed model of the large-scale transition from the laboratory to the full-scale prototype are identified.*

Keywords: *Physical model, Laboratory prototype, Greenhouse, Dimension, Computerized technologies.*

Introduction

At present, a wide range of scientific and technical research is devoted to the problem of developing computerized technologies for studying production processes in the agricultural segment of national economies. The relevance of research in this field is determined by high indicators of science intensity of modern greenhouse vegetable production and insufficiency of fundamental research results in the field of plant biochemistry and physiology [20]. One of the most promising approaches to improving greenhouse vegetable production is creation and implementation of modern computerized information and measurement systems for monitoring and control over parameters of greenhouse microclimate.

Industrial greenhouse complexes are complex engineering structures that should provide control over microclimate parameters that affect the efficiency of evapotranspiration and photosynthesis processes, there by determining rates of growth, volume and quality of production of greenhouse vegetable production. Nowadays, methods of mathematical and physical modelling of biophysical and biochemical processes taking place in greenhouse complexes are increasingly being used as means of interpreting results of complex experimental studies and observations.

Significant progress in the improvement of modelling methods, as well as their successful application, is determined by high rates of technological development in solving problems of numerical modelling of processes occurring during greenhouse vegetable production in agroecosystems.

Thus, industrial greenhouse complexes should be equipped with state-of-the-art sensory, microprocessor and infocommunication technologies, which are integrated into information and measurement systems at hardware and algorithmic levels. The main types of modern active and passive technologies with a detailed analysis of their main characteristics that are currently used in greenhouse conditions are presented in publications [11, 12, 14, 26].

The results of these studies can be used to substantiate the structural and algorithmic organization of a computerized information and measurement system for monitoring and control over greenhouse microclimate using the scale transformation method.

The use of modern sensory, computerized and infocommunication technologies for monitoring and control over microclimate parameters of greenhouses will allow us to make the transition from the phenomenological approach to greenhouse vegetable production to the use of quantitative methods based on the use of simulation models and mathematical procedures [17, 19]. Having analysed characteristics of greenhouses as control objects we concluded that the rationale for the structural and algorithmic organization of a computerized monitoring and control system for greenhouse microclimate is a science-intensive and non-standard procedure. Optimal control over the processes of greenhouse production requires using equations of mathematical physics, which describe dynamic processes of balance of mass and energy taking into account the processes of diffusion and convection [18].

Thus, one of the most urgent tasks in solving the problem of increasing the efficiency of greenhouse complexes is providing a rationale for the structural and algorithmic organization of a computerized monitoring and control system for microclimate parameters. A condition necessary and sufficient for implementing the obtained laboratory test results in conditions of greenhouse complexes is scale transition from the laboratory prototype (physical model) to the full-scale prototype by applying the mathematical apparatus of the similarity theory.

The research results presented in this article are devoted to solving the following scientific and applied problem: limitations of the physico-mathematical means of extrapolating results of laboratory observations of the greenhouse microclimate dynamics to real industrial greenhouse complexes, which causes insufficient efficiency of designing and implementing computerized technologies in greenhouse vegetable production.

The purpose of the article is to provide a rationale for scientific and practical approaches to development and research of the structural and algorithmic organization of computerized monitoring and control systems for greenhouse microclimate by the scale transformation method. The target of the research is the process of a large-scale transition from a laboratory prototype (physical model) to a full-scale prototype of a monitoring and control system for greenhouse microclimate parameters by applying the mathematical means of the similarity theory. The research subject is methods and means of physical modelling of computerized monitoring and control systems for technological processes in greenhouse vegetable production.

The innovativeness of the results obtained is as follows:

- A novel physico-mathematical model of the scale transition from the laboratory prototype to the full-scale prototype of the monitoring and control system for greenhouse microclimate parameters by the dimensional analysis method has been substantiated.
- A method of physical modelling of the dynamics of physicochemical parameters of greenhouse microclimate has been further developed, which, unlike existing ones, takes into account the complex effect of the regulated list of controlled quantities on the efficiency of photosynthesis of greenhouse crops.
- Structural and algorithmic organization of a computerized information and measurement system for monitoring and control over the microclimate of industrial greenhouses, which takes into account the current trends in the development of infocommunication, sensory and microprocessor technologies, has been improved.

The obtained research results can be integrated into methods and means of computerized monitoring and control of automatic stationary complexes to maintain optimal conditions for growing crops in industrial greenhouse complexes.

Materials and methods

Simulation method

At present, two main methods are used to solve the problems of developing physical models of technical processes and objects [8, 9, 21, 25], which are presented in Table 1. The analysis of existing research results on the development of mathematical models of the dynamics of greenhouse microclimate parameters [2, 7, 16, 23] made it possible to establish the absence of a generalized model that describes the complex effect of microclimate physicochemical parameters on the efficiency of greenhouse vegetable production. Therefore it is impossible to make a model of the process of greenhouse microclimate parameter dynamics in the form of a system of differential equations.

Table 1. Existing methods of physical modelling

Method	Key features
Method of reduction of differential equations (analytical method)	Requires availability of complete a priori information about the object (process) of modelling in the form of corresponding differential equations of mathematical physics; complexity and labour intensity of detailed mathematical analysis.
Method of analyzing the dimensions of physical quantities (the Rayleigh-Pavlushenko method)	Applicable for obtaining criteria and criterial equations for complex processes for which it is not possible to compose differential equations and formulate the conditions for single-valuedness.

Thus, the use of the method of reduction of differential equations is impossible when solving the stated research problem. Consequently, this fact allows developing a model for a scale transition from a laboratory prototype to a full-scale prototype of a monitoring and control system over greenhouse microclimate parameters using the method of analyzing the dimensions of physical quantities.

A generalized algorithm for the process of providing a rationale behind the model of a scale transition from a laboratory prototype to a full-scale prototype of a monitoring and control system for the greenhouse microclimate parameters using the method of analyzing the dimensions of physical quantities is shown in Fig. 1.

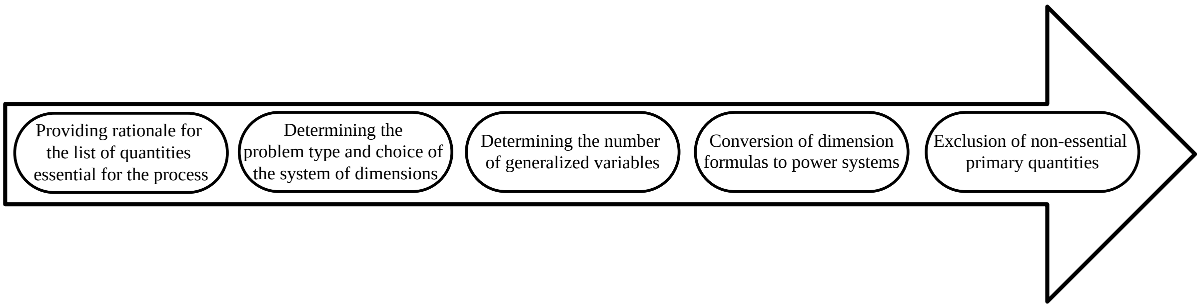


Fig. 1 Generalized algorithm for providing a rationale behind the model of a scale transition

According to the third theorem of Kirpichev [9], physical systems can be considered similar when there is geometric, kinematic and dynamic similarity. Thus, while developing a model for large-scale transition from a laboratory prototype to a full-scale prototype of the monitoring and control system for greenhouse microclimate parameters, a number of mandatory requirements must be taken into account [9, 25], which are shown in Fig. 2 in the form of a block diagram. Thus, based on the analysis of the algorithm shown in Fig. 1, it is established that the first step in solving the problem of validating the large-scale transition model of the system under investigation is establishing a list of values essential for greenhouse vegetable production.

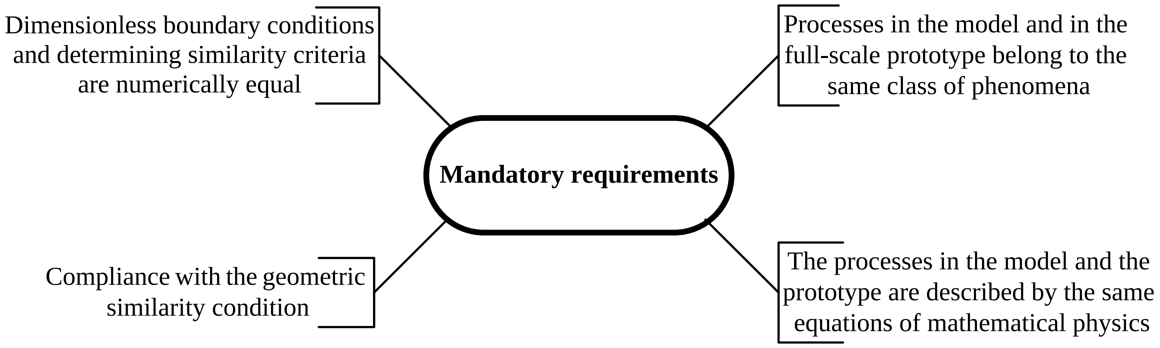


Fig. 2 Mandatory requirements for development of a large-scale transition model

List of influencing parameters

The analysis of the existing research results and current regulatory documentation in the field of greenhouse vegetable production (see Table 2) allowed us to establish a set of microclimate parameters, which the efficiency of greenhouse production depends on to the greatest extent. Also, by analyzing the specialist literature on greenhouse vegetable production [13, 15, 22], it was found that the intensity index of photosynthesis can be used as an integral characteristic of the complex effect of microclimate parameters on the efficiency of greenhouse production. Thus, based on the analysis of the data presented in Table 2, we can derive the basic model structure of the influence of the physicochemical microclimate parameters on the efficiency of growing crops in industrial greenhouse complexes.

Table 2. Set of microclimate parameters subjected to the measurement control

List of microclimate parameters subjected to the measurement control	Scientific source
air temperature, air humidity, concentration of carbon dioxide in the cultivation area, air velocity in the cultivation area, illumination of the cultivation area	[1]
air temperature, air humidity, concentration of carbon dioxide in the cultivation area, air velocity in the cultivation area, illumination of the cultivation area, soil temperature, soil acidity, soil salinity	[6]
air temperature in the crop cultivation area, air humidity in the crop cultivation area, soil temperature in the root layer, soil moisture in the root layer, solution temperature at watering, effective illumination of the crop cultivation areain the visible optical range, taking into account daily dynamics of natural light, concentration of carbon dioxide in the cultivation area, permissible content of salts and ions in the irrigation solution, air velocityin the cultivation area	[3, 4]

Basic structure of the model

Based on the analysis of the characteristic features of the existing methods of physical modelling in the subsection *Simulation method*, it was established that in order to obtain similarity criteria, the method of analysis of the dimensions of physical quantities (the Rayleigh-Pavlushenko method) was used in the article. In order to determine the type of problem and the choice of a dimension system, and to determine the number of generalized variables, it was established that growth regimes of greenhouse crops are dynamic characteristics and that monitoring of the main microclimate parameters is carried out using computerized means. Therefore, the model under study should be presented in a discrete form, in which time is an independent variable.

The input of the model receives signals from the sensors declared in Table 2 of the physicochemical microclimate parameters, and the output function is the intensity of photosynthesis of greenhouse crops.

Consequently, the generalized basic structure of the model can be represented in the form of the following defining equation:

$$Z_{phot}(i) = f\left\{T_{air}(i), W_{air}(i), T_{soil}(i), W_{soil}(i), T_{solution}(i), E_{area}(i), C_{solution}(i), V_{air}(i), C_{CO_2}(i)\right\}, \quad (1)$$

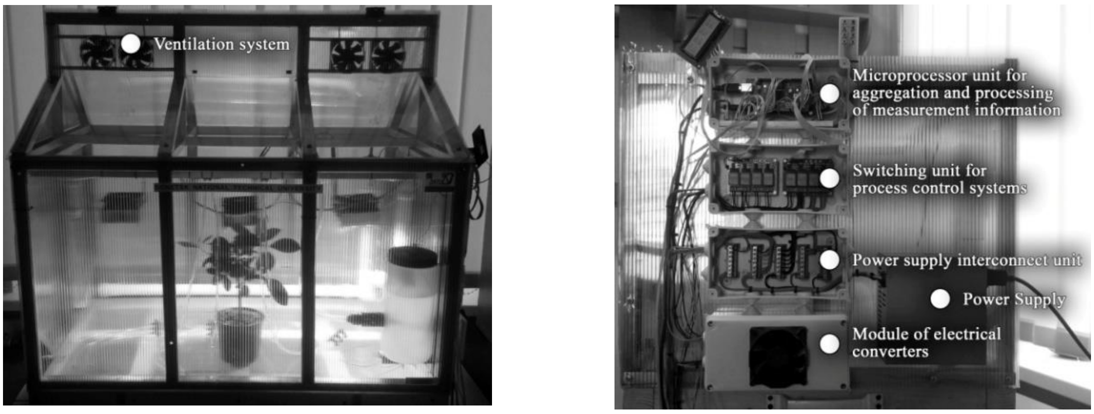
where Z_{phot} is the intensity of photosynthesis; i – sample spacing of the prototype; T_{air} – air temperature in the cultivation area; W_{air} – air humidity in the cultivation area; T_{soil} – soil temperature in the root layer; W_{soil} – soil humidity in the root layer; $T_{solution}$ – solution temperature at watering; E_{area} – effective illumination of the cultivation area; $C_{solution}$ – total content of salts and ions; V_{air} – air velocity in the cultivation area; C_{CO_2} – concentration of carbon dioxide in the cultivation area.

Results and discussion

Based on the a priori information, which is given in the section *Materials and methods*, a laboratory installation of an automated greenhouse was designed and created in the laboratory of information measurement systems of the Department of Electronic Engineering of State Higher Educational Establishment “Donetsk National Technical University”, the appearance of which is shown in Fig. 3. Taking into account the requirements for the method of developing the large-scale transition model [9, 25], the geometric similarity condition is met for the realized laboratory prototype, which is a prerequisite for carrying out studies on the justification of the structural and algorithmic organization of a computerized monitoring and control system for greenhouse microclimate parameters using the scale transformation method. The constant of linear similarity of the model-full-scale prototype is equal to:

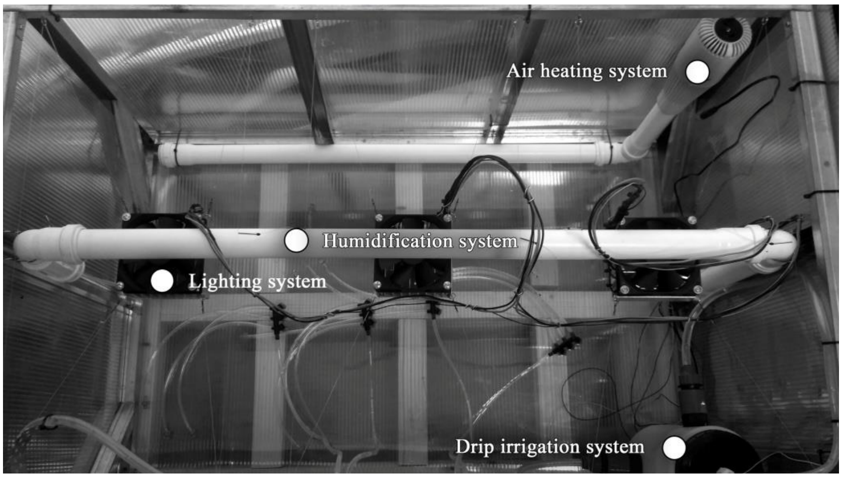
$$k_l = \frac{h_{real}}{h_{model}} = \frac{a_{real}}{a_{model}} = \frac{b_{real}}{b_{model}} = 65, \tag{2}$$

where k_l is the linear similarity constant; h_{real}, a_{real}, b_{real} are height, length and width of a standard vegetable uneven span of year-round greenhouses, respectively; h_{model}, a_{model}, b_{model} are height, length and width of the realized model of the automated greenhouse, respectively.



a) general view of the automated greenhouse model (front view)

b) the electrical component of the automated greenhouse model (side view)



c) appearance of technological systems (top view)

Fig. 3 Laboratory installation of the automated greenhouse

The installation is equipped with the following technological systems: drip irrigation, ventilation, artificial illumination, heating and humidification of air, which satisfies the mandatory condition of the ratio of processes in the model and the full-scale prototype to one class of phenomena.

To implement the large-scale transition from the laboratory prototype to the full-scale prototype of the monitoring and control system for greenhouse microclimate parameters, we consider the functional dependence Eq. (1). When using the method of analyzing the dimensions of physical quantities, a correspondence must be made between metric and physical transformations of the Eq. (1). Thus, the only possible variant of the function representation Eq. (1) is its representation in the form of a product of the argument that is included in it, at a fixed point in time in some exponents of power [10]:

$$Z_{phot} = \alpha \cdot T_{air}{}^{A_1} \cdot W_{air}{}^{A_2} \cdot T_{soil}{}^{A_3} \cdot W_{soil}{}^{A_4} \cdot T_{solution}{}^{A_5} \cdot E_{area}{}^{A_6} \cdot C_{solution}{}^{A_7} \cdot V_{air}{}^{A_8} \cdot C_{CO_2}{}^{A_9}, \tag{3}$$

where A_1, ..., A_9 are the exponents of power used to transform the equation into a dimensionless form; α is the constant component of the large-scale transition model.

The next step in the implementation of the large-scale transition model is replacement of the physical quantities Eq. (3) with their dimensions using the standard System of Units (SI). Also, taking into account that the soil moisture (W_{soil}) and air moisture (W_{air}) are uniquely determined through the mass of moisture in the soil (m_{soil}) and air (m_{air}), respectively, then:

$$\begin{gathered} Z_{phot}, [\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}];\ T_{air}, [\text{K}];\ m_{air}, [\text{kg}];\ T_{soil}, [\text{K}];\ m_{soil}, [\text{kg}];\ T_{solution}, [\text{K}]; \\ E_{area}, [\text{W} \cdot \text{m}^{-2} = \text{kg} \cdot \text{m}^{2} \cdot \text{m}^{-2} \cdot \text{s}^{-3} = \text{kg} \cdot \text{s}^{-3}];\ C_{solution}, [\text{kg} \cdot \text{m}^{-3}];\ V_{air}, [\text{m} \cdot \text{s}^{-1}];\ C_{CO_2}, [\text{kg} \cdot \text{m}^{-3}]. \end{gathered} \tag{4}$$

Substituting in Eq. (3) instead of physical quantities the system of their dimensions Eq. (4), taking into account the replacement of the moisture parameter by the moisture mass, we obtain:

$$\begin{gathered} \left(\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}\right) = \alpha \cdot (\text{K})^{A_1} \cdot (\text{kg})^{A_2} \cdot (\text{K})^{A_3} \cdot (\text{kg})^{A_4} \cdot (\text{K})^{A_5} \times \\ \times \left(\text{kg} \cdot \text{s}^{-3}\right)^{A_6} \cdot \left(\text{kg} \cdot \text{m}^{-3}\right)^{A_7} \cdot \left(\text{m} \cdot \text{s}^{-1}\right)^{A_8} \cdot \left(\text{kg} \cdot \text{m}^{-3}\right)^{A_9}. \end{gathered} \tag{5}$$

Since the left and right sides of Eq. (5) must be equal for each unit of measurement, we can write the following system of equations for the exponents for the same physical quantities:

$$\begin{cases} 0 = A_1 + A_3 + A_5, \text{ for 'K'}; \\ 1 = A_2 + A_4 + A_6 + A_7 + A_9, \text{ for 'kg'}; \\ -2 = -3A_7 + A_8 - 3A_9, \text{ for 'm'}; \\ -1 = -3A_6 - A_8, \text{ for 's'}. \end{cases} \tag{6}$$

The resulting system of Eq. (6) imposes restrictions on the physical quantities Eq. (5), and also takes into account the relationships between these quantities, which are expressed by their dimensions.

In this case, the system of Eq. (6) is algebraically insufficient, since it contains four equations with the number of unknowns equal to nine. Possible combinations of variable representation are given in Table 3.

The next step in the solution of the problem is the choice of one of the possible variants of representing independent variables.

Table 3. Variants of presentation of variables

Initial equation	**Possible variant of representation**
$0 = A_1 + A_3 + A_5$	$\left[\begin{array}{l} A_1 = -A_3 - A_5; \\ A_3 = -A_1 - A_5; \\ A_5 = -A_1 - A_3. \end{array}\right.$
$1 = A_2 + A_4 + A_6 + A_7 + A_9$	$\left[\begin{array}{l} A_2 = 1 - A_4 - A_6 - A_7 - A_9; \\ A_4 = 1 - A_2 - A_6 - A_7 - A_9; \\ A_6 = 1 - A_2 - A_4 - A_7 - A_9; \\ A_7 = 1 - A_2 - A_4 - A_6 - A_9; \\ A_9 = 1 - A_2 - A_4 - A_6 - A_7. \end{array}\right.$
$-2 = -3A_7 + A_8 - 3A_9$	$\left[\begin{array}{l} A_7 = \dfrac{2 + A_8 - 3A_9}{3}; \\ A_8 = -2 + 3A_7 + 3A_9; \\ A_9 = \dfrac{2 + A_8 - 3A_7}{3}. \end{array}\right.$
$-1 = -3A_6 - A_8$	$\left[\begin{array}{l} A_6 = \dfrac{1 - A_8}{3}; \\ A_8 = 1 - 3 \cdot A_6. \end{array}\right.$

In our case, taking into account the preliminary analysis, A_1, A_2, A_7 and A_8 are chosen as variables, which are expressed through A_3, A_4, A_5, A_6 and A_9. Thus, we obtain:

$$\begin{cases} A_1 = -A_3 - A_5; \\ A_2 = 1 - A_4 - A_6 - A_7 - A_9; \\ A_7 = \dfrac{2 + A_8 - 3A_9}{3}; \\ A_8 = 1 - 3A_6. \end{cases} \tag{7}$$

Substituting Eq. (7) for the variables A_1, A_2, A_7 and A_8 into Eq. (5), having previously expressed in the third equation A_8 through A_6 and in the second equation A_7 through A_6 and A_9, we get:

$$\begin{aligned} &\left(\mathrm{kg} \cdot \mathrm{m}^{-2} \cdot \mathrm{s}^{-1}\right) = \alpha \cdot (\mathrm{K})^{-A_3 - A_5} \cdot (\mathrm{kg})^{1 - A_4 - A_6 - 1 + A_6 + A_9 - A_9} \cdot (\mathrm{K})^{A_3} \cdot (\mathrm{kg})^{A_4} \cdot (\mathrm{K})^{A_5} \times \\ &\times \left(\mathrm{kg} \cdot \mathrm{s}^{-3}\right)^{A_6} \cdot \left(\mathrm{kg} \cdot \mathrm{m}^{-3}\right)^{1 - A_6 - A_9} \cdot \left(\mathrm{m} \cdot \mathrm{s}^{-1}\right)^{1 - 3A_6} \cdot \left(\mathrm{kg} \cdot \mathrm{m}^{-3}\right)^{A_9}. \end{aligned} \tag{8}$$

Performing an inverse transition from dimensions to physical quantities, and also having previously grouped the parameters with the same exponents, we get:

$$Z_{phot} = \underbrace{V_{air}\cdot C_{solution}}_{\alpha}\cdot\left(\frac{T_{soil}}{T_{air}}\right)^{A_3}\left(\frac{W_{soil}}{W_{air}}\right)^{A_4}\left(\frac{T_{solution}}{T_{air}}\right)^{A_5}\left(\frac{E_{area}}{C_{solution}\cdot\left(V_{air}\right)^3}\right)^{A_6}\left(\frac{C_{CO2}}{C_{solution}}\right)^{A_9}. \tag{9}$$

To further study the model of a large-scale transition from the laboratory prototype to the full-scale prototype, it is necessary to fulfill the condition of numerical equality of the characteristic criteria in the model and the full-scale prototype, namely:

$$\frac{T_{air}^{real}}{T_{air}^{model}} = k_{air}^{T};\ \frac{W_{air}^{real}}{W_{air}^{model}} = k_{air}^{W};\ \frac{T_{soil}^{real}}{T_{soil}^{model}} = k_{soil}^{T};\ \frac{W_{soil}^{real}}{W_{soil}^{model}} = k_{soil}^{W};\ \frac{T_{solution}^{real}}{T_{solution}^{model}} = k_{solution}^{T};$$

$$\frac{E_{area}^{real}}{E_{area}^{model}} = k_{area}^{E};\ \frac{C_{solution}^{real}}{C_{solution}^{model}} = k_{solution}^{C};\ \frac{V_{air}^{real}}{V_{air}^{model}} = k_{air}^{V};\ \frac{C_{CO_2}^{real}}{C_{CO_2}^{model}} = k_{CO_2}^{C}.$$

Based on the above, we obtain the following model of the large-scale transition from the laboratory prototype to the full-scale prototype of the monitoring and control system for greenhouse microclimate parameters:

$$Z_{phot} = \underbrace{k_{air}^{V}k_{solution}^{C}}_{\alpha}\left(\frac{k_{soil}^{T}}{k_{air}^{T}}\right)^{A_3}\left(\frac{k_{soil}^{W}}{k_{air}^{W}}\right)^{A_4}\left(\frac{k_{solution}^{T}}{k_{air}^{T}}\right)^{A_5}\left(\frac{k_{area}^{E}}{k_{solution}^{C}\cdot\left(k_{air}^{V}\right)^3}\right)^{A_6}\left(\frac{k_{CO_2}^{C}}{k_{solution}^{C}}\right)^{A_9}, \tag{10}$$

where k_{air}^{V}, k_{air}^{W}, $k_{solution}^{C}$, k_{soil}^{T}, k_{air}^{T}, $k_{solution}^{T}$, k_{soil}^{W}, k_{area}^{E}, $k_{CO_2}^{C}$ are the characteristic criteria for physical similarity of the model-full-scale prototype of the system under study.

In order to obtain the final form of the model of the large-scale transition in Eq. (10), we introduce the following notation:

$$\alpha = k_{air}^{V}k_{solution}^{C};\ P_1 = \frac{k_{soil}^{T}}{k_{air}^{T}};\ P_2 = \frac{k_{soil}^{W}}{k_{air}^{W}};\ P_3 = \frac{k_{solution}^{T}}{k_{air}^{T}};\ P_4 = \frac{k_{area}^{E}}{k_{solution}^{C}\left(k_{air}^{V}\right)^3};\ P_5 = \frac{k_{CO_2}^{C}}{k_{solution}^{C}}.$$

Thus, taking into account the above-mentioned notations and imposed restrictions, the final developed model of the large-scale transition from the laboratory prototype to the full-scale prototype of the monitoring and control system for greenhouse microclimate parameters is as follows:

$$Z_{phot} = \alpha\left(P_1\right)^{A_3}\left(P_2\right)^{A_4}\left(P_3\right)^{A_5}\left(P_4\right)^{A_6}\left(P_5\right)^{A_9}, \tag{11}$$

where P_1, P_2, P_3, P_4, P_5 are the similarity criteria presented in the form of dimensionless complexes.

On account of the analysis of Eq. (11), it is evident that for nine factors influencing the efficiency of photosynthesis, a model consisting of five characteristic criteria was obtained. And similarity criteria P_1, P_2, P_3 determine the condition of dynamic similarity of the model and full-scale prototype, and P_4 and P_5 determine kinematic similarity. The proposed general view of the large-scale transition model Eq. (11) made it possible to prove the necessity of continuous monitoring of physicochemical greenhouse microclimate parameters influencing the efficiency of photosynthesis which are given in Table 2. This fact justifies the requirement of introducing measuring channels of physicochemical parameters into the structure of the computerized monitoring and control system for the greenhouse microclimate, as well as the need to maintain them at the regulated level [1, 3, 4, 6], using modern microprocessor technologies to automate technological processes for greenhouse vegetable production. The proposed structural-algorithmic organization of the computerized system under consideration, taking into account modern requirements for the construction of adaptive information measurement systems [5, 24, 27], is shown in Fig. 4.

This development has a modular structure and performs the following functions: collection of primary measurement information from the measuring channels of the system; analog processing of sensor output signals of physical and chemical parameters with subsequent conversion to digital form; averaging the monitoring results and calculating the values of digital signals in units of physical and chemical quantities; local indication of results and their accumulation in a database on a remote server; generation of control signals by modules for maintaining technological processes of drip irrigation, ventilation, artificial illumination, heating and air humidification.

The developed system is universal and provides the possibility of working with a different number of measuring channels. The program has a function of adapting the basic technological regimes of growing crops to their types and periods of vegetation. To conduct further research on obtaining a specific form of Eq. (11), it is necessary to carry out a series of experimental studies on the algorithm shown in Fig. 5.

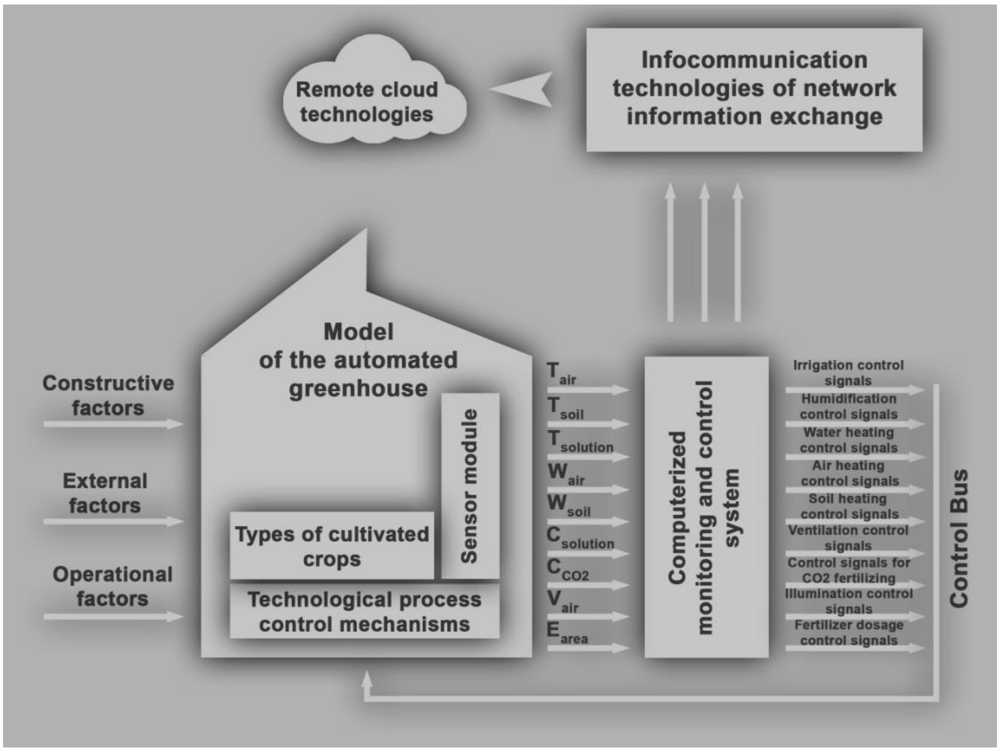


Fig. 4 Structural-algorithmic organization of the system

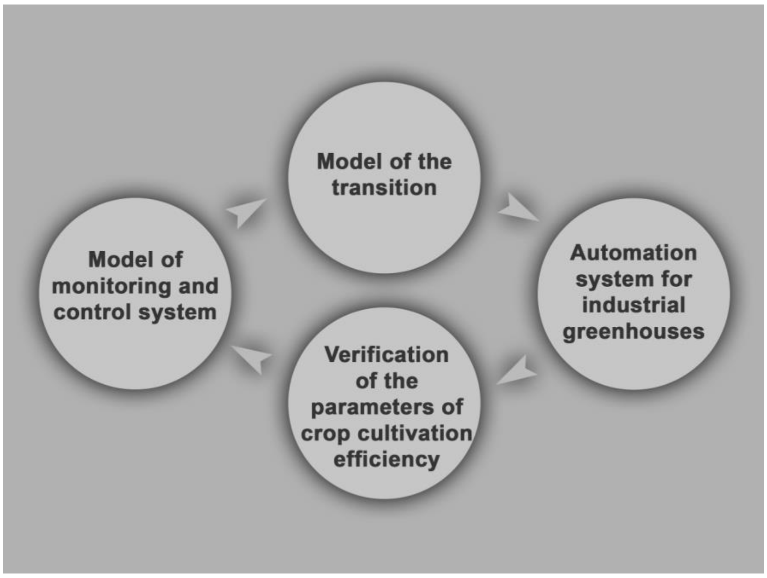


Fig. 5 Algorithm for priority research directions

The main promising areas of research on providing the rationale for the structural-algorithmic organization of the monitoring and control computerized system for greenhouse microclimate parameters using the large-scale transformation method are:

- accumulation of the base of experimental observations of the dynamics of physicochemical greenhouse microclimate parameters with their subsequent mathematical analysis for obtaining specific types of dependence Eq. (11) for different types and periods of crop vegetation;
- introduction of adaptive high-performance methods and means of aggregation and processing of measurement information on the dynamics of physicochemical greenhouse microclimate parameters in real time;
- optimization of the structural-algorithmic organization of the computerized information and measurement system for monitoring and control over microclimate parameters of industrial greenhouse complexes;
- establishing a rationale for scientific and practical bases of complex influence of greenhouse microclimate parameters, which are distributed in space and time, on quality indicators, rates and volumes of greenhouse vegetable production.

Conclusion

The article presents the research results devoted to the solution of the current scientific and applied problem on the improvement of the physical-mathematical apparatus of extrapolating the results of laboratory observations of the dynamics of greenhouse microclimate to real industrial greenhouse complexes. The findings made it possible to increase the efficiency of designing and introducing computerized technologies in greenhouse vegetable production.

The obtained research results allowed us to provide the rationale for the scientific and practical approaches to development and optimization of the structural-algorithmic organization of the computerized monitoring and control system for greenhouse microclimate parameters using the large-scale transformation method, namely, the rationale for the physical-mathematical model of the large-scale transition from the laboratory prototype to the full-scale prototype of the system based on the dimensional analysis method; to improve the method of physical modelling of dynamics of physicochemical greenhouse microclimate parameters; to synthesize the structural-algorithmic organization of the computerized information and measurement system, taking into account the current trends in the development of infocommunication, sensory and microprocessor technologies.

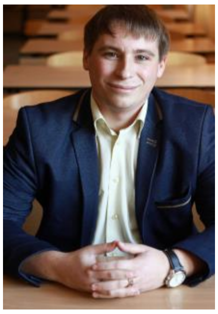
The necessity of conducting further studies of the proposed model of the large-scale transition from the laboratory prototype to the full-scale prototype of the monitoring and control system for greenhouse microclimate parameters, as well as confirmation of the adequacy of the implementation of development on the yields of greenhouse crops by conducting complex experimental and theoretical studies on establishing the regularities of the integral influence of the greenhouse microclimate on indicators of quality, rates and volumes of greenhouse vegetable production, was proved.

References

1. American National Standard ANSI/ASAE EP406.4 (2008). Heating, Ventilating and Cooling Greenhouses, American Society of Agricultural and Biological Engineers, Saint Joseph.
2. Chen J., Ya. Cai, F. Xu, H. Hu, Q. Ai (2014). Analysis and Optimization of the Fan-pad Evaporative Cooling System for Greenhouse Based on CFD, Advances in Mechanical Engineering, 6, 1-8.
3. Departmental Rules of the Technological Engineering NTP 10-95 (1996). Norms of Technological Designing Greenhouses and Greenhouse Combines for Growing Vegetables and Sprouts, Giproniselprom, Moscow (in Russian).
4. Departmental Rules of the Technological Engineering VNTP APK-19-07 (2007). Greenhouse and Greenhouse Businesses. Structures Protected Ground for Farming (Rural) Farm, HIK, Kiev (in Ukrainian).
5. Dong T. (2017). Assessment of Data Reliability of Wireless Sensor Network for Bioinformatics, Int J Bioautomation, 27(3), 241-250.
6. FAO Plant Production and Protection 230 (2017). Good Agricultural Practices for Greenhouse Vegetable Production in the South East European Countries, Food and Agriculture Organization of the United Nations (FAO), Quebec.
7. Fitz-Rodríguez E., C. Kubota, G. Giacomelli, M. Tignor, S. Wilson, M. McMahon (2010). Dynamic Modeling and Simulation of Greenhouse Environments under Several Scenarios: A Web-based Application, Comp and Electr in Agriculture, 70(1), 105-116.
8. Frishter L. U. (2016). Application of the Methods of the Theory Similarity and Dimensional Analysis for Research the Local Stress-strain State in the Neighborhood of an Irregular Point of the Boundary, Procedia Engineering, 153, 151-156.
9. Gatapova N. C., A. N. Koliuh, N. V. Orlova, A. Yu. Orlov (2014). Fundamentals of the Theory and Technique of Physical Modelling and Experiment: A Tutorial, Tambov State Technical University, Tambov (in Russian).
10. Guhman A. A. (1973). Introduction to the Theory of Similarity, 2nd Edition, Textbook, Higher School, Moscow (in Russian).
11. Harjunowibowo D., E. Cuce, S. Omer, S. Riffat (2016). Recent Passive Technologies of Greenhouse Systems: A Review, 15th International Conference on Sustainable Energy Technologies, National University of Singapore, 1-10.
12. Harjunowibowo D., Y. Ding, S. Omer, S. Riffat (2018). Recent Active Technologies of Greenhouse Systems – A Comprehensive Review, Bulg J Agric Sci, 24(1), 158-170.
13. Ji Y. H., Y. Q. Jiang, T. Li, M. Zhang, Sh. Sha, M. Z. Li (2016). An Improved Method for Prediction of Tomato Photosynthetic Rate Based on WSN in Greenhouse, Int J Agric & Biol Eng, 9(1), 146-152.
14. Jørgensen M. H. (2018). Agricultural Field Production in an ‘Industry 4.0’ Concept, Agronomy Research, 16(1), 94-102.

15. Keulen H. van, E. Dayan (1993). TOMGRO: A Greenhouse – Tomato Simulation Model, Centre for Agrobiological Research, Wageningen.
16. Koshkin D., I. Pavlyuchenko (2012). Mathematical Model of Microclimate Control of Mushroom Greenhouse, Bulletin of the Agrarian Science of the Black Sea Region, 1(65), 165-170 (in Ukrainian).
17. Laktionov I., O. Vovna, A. Zori (2017). Concept of Low Cost Computerized Measuring System for Microclimate Parameters of Greenhouses, Bulg J Agric Sci, 23(4), 668-673.
18. Laktionov I., O. Vovna, O. Cherevko, T. Kozlovskaya (2018). Mathematical Model for Monitoring Carbon Dioxide Concentration in Industrial Greenhouses, Agronomy Research, 16(1), 134-146.
19. Laktionov I. S, O. V. Vovna, A. A. Zori (2017). Planning of Remote Experimental Research on Effects of Greenhouse Microclimate Parameters on Vegetable Crop-Producing, Int J on Smart Sensing and Intelligent Systems, 10(4), 845-862.
20. Poluehktov R. A., Eh. I. Smolyar, V. V. Terleev, A. G. Topazh (2006). Models of the Production Process in Agriculture, St. Petersburg University Publishing House, St. Petersburg (in Russian).
21. Sonin A. (1992). The Physical Basis of Dimensional Analysis, Department of Mechanical Engineering, MIT, Cambridge.
22. Tikhomirov A. A., V. P. Sharupich, G. M. Lisovskiy (2000). Plant Photoculture: Biophysical and Biotechnological Fundamentals: Training Manua, Publishing House of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk (in Russian).
23. Tsmots I., T. Tesliuk (2016). Structure and Models of Microclimate Control System of a Mini-greenhouse, Bulletin of Lviv Polytechnic National University, Computer Science and Information Technology, 843, 228-237 (in Ukrainian).
24. Vassileva S., G. Georgiev, S. Mileva (2005). Knowledge-based Control Systems via Internet. Part I. Applications in Biotechnology, Int J Bioautomation, 2, 37-48.
25. Venikov V. A. (1976). Theory of Similarity and Modelling (Applied to Problems in Electrical Energy Industry): A Textbook for Higher Schools, Higher School, Moscow (in Russian).
26. Vovna O., I. Laktionov, S. Sukach, M. Kabanets, E. Cherevko (2018). Method of Adaptive Control of Effective Energy Lighting of Greenhouses in the Visible Optical Range, Bulg J Agric Sci, 24(2), 335-340.
27. Zhou Sh., L. Zhong (2016). Research of Wireless Sensor Monitoring Network of Melon Fly under Different Temperatures and Other Environmental Conditions, Int J Bioautomation, 20(1), 125-134.

Assoc. Prof. Ivan Laktionov, Ph.D.
E-mail: ivan.laktionov@donntu.edu.ua



He received a M.Sc. Degree in Electronic Systems from Donetsk National Technical University (DonNTU) in 2012 and a Ph.D. Degree in Engineering (2015), majoring in Computer Systems and Components from the State Higher Educational Establishment (SHEE) DonNTU. Since 2016 he has been working as an Associate Professor of the Department of Electronic Engineering of the SHEE DonNTU. His research interests include development of advanced technologies for improving efficiency of computerized monitoring and control of microclimate parameters of industrial greenhouses.

Oleksandr Vovna, D.Sc.
E-mail: oleksandr.vovna@donntu.edu.ua

He received his M.Sc. Degree in Electronic Systems from Donetsk National Technical University in 2004, a Ph.D. Degree in Engineering (2009) and a Doctorate in Engineering (2015), majoring in Computer Systems and Components from the SHEE DonNTU. He is a Head of the Department of Electronic Engineering of the SHEE DonNTU. His research interests include development of methods and tools to improve the accuracy and speed of information and measurement systems for concentration of gas components.

Volodymyr Bondarenko, D.Sc.
E-mail: nv1287@ukr.net

He received his Specialist's Degree in Vocational Training from Sloviansk State Pedagogical Institute in 1996, Ph.D. Degree in Technology (2003) and D.Sc. in Pedagogy (2016). He is a Head of Department of General Technical Disciplines, Safety of Vital Activity and Automotive Engineering of SHEE Donbas State Pedagogical University. His research interests include development of methods for regulating the operation modes of line magnetohydrodynamic machines and development of future technology teachers' professional image.

Prof. Anatolii Zori, D.Sc.
E-mail: anatolii.zori@donntu.edu.ua

He received the qualification of an Electrical Engineer in Automatics and Telemechanics from Donetsk Polytechnic Institute in 1964, the Scientific Degree of Candidate of Technical Sciences (1972) from All-Union Scientific Research Institute of Metrology and a Doctorate in Information and Measurement Systems (1992). He is a Professor of the Department of Electronic Engineering of the SHEE DonNTU. His research interests include improving accuracy, speed and reliability of information and measurement systems.

Vladyslav Lebediev, M.Sc. Student
E-mail: vladyslav.lebediev@donntu.edu.ua

He received a B.Sc. Degree in Electronic Systems from Donetsk National Technical University in 2017. Currently, he is studying for a M.Sc. Degree in Electronic Systems. The basic direction of scientific activity is methods and means of parameters controlling of the industrial greenhouses microclimate, as well as microprocessor technology.