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A hybrid system with intelligent control for the processes of resource and energy supply of a greenhouse complex with application of energy renewable sources

***Abstract**. The algorithm of control for the regime of artificial supplementary lighting of plants can secure the light regime, according to their kind and phase of vegetation growth. A peculiarity of the proposed algorithm suggests use of the information about a short-term weather forecast, which supplies the maximum employment of solar radiation energy in the technological process of artificial lighting of plants.*

Streszczenie.** Algorytm sterowania dla systemu sztucznego doświetlania roślin można zastosować w systemie oświetlenia, w zależności od fazy wzrostu roślinności i ich rodzaju. Specyfika proponowanego algorytmu sugeruje wykorzystanie informacji o krótkoterminowej prognozie pogody, która zapewnia maksymalne wykorzystanie energii promieniowania słonecznego w procesie technologicznym sztucznego oświetlenia roślin. System hybrydowy z inteligentnym sterowaniem procesami zaopatrzenia w energię kompleksu szklarniowego z zastosowaniem odnawialnych źródeł energii.* ***Hybrydowy algorytm sterowania dla systemu sztucznego doświetlania roślin

Keywords: intelligent control, smart greenhouse, renewable energy, energy supply, data transfer.
Słowa kluczowe: inteligentne sterowanie, inteligentna szklarnia, energia odnawialna, źródło energii, transfer danych.

Introduction

Modern agrarian production is an advanced technological branch of the economy, which suggests continuous regulation of a set of production indices, immediately influencing efficiency of production and the quality of the final product.

The problem of optimization of the parameters of production environment is particularly urgent for crop production on covered soil, because of the increased number of controlling parameters and their intensive impact on the final product. Thus, the systems of automatic or computer-aided operation of greenhouse equipment are actively developed and practically used. In particular, the work [1] presents the information about the development conceptions of the control system of the technological process of plant growing on the covered soil, including depiction of possible technical solutions. The [2] considers innovative establishment technologies of the automatic system of control of greenhouse parameters, particularly, the issue of modeling, development of technical means of control and management, including robotics, as well as the issue of optimization.

The modern automatization tendency of covered soil constructions confirms the transfer to the local and flexible readjusted systems, which are based on the use of sensors and microcontrollers, e.g. of Arduino family [3], Raspberry-Pi [4]. In those systems, it is expedient to use the technologies of wireless data transmission and the Internet of things [4, 5, 6].

It is worth noting that the process of agricultural crop growing in the greenhouse complexes is energy- and resources-consuming [7]. Hence, a growing number of enterprises endeavor to attract renewable source of energy to support microclimate, particularly the required level of lighting in the greenhouses [8]. A common practice suggests application of thermal pumps in the systems of heat supply for the covered soil constructions, as it is demonstrated in [9].

In the intelligent control systems of the technological processes, as well as management of the energy flows of renewable sources of energy, they apply the algorithm of fuzzy logic [10].

Thus, it is possible to assume that the systems efficiency of automatic control of the technological processes in the covered soil constructions can be improved by introducing automatic micro-processor systems with application of the instruments of fuzzy logic, which can support an adaptive energy supply due to application of the renewable sources of energy along with establishment of the necessary parameters of microclimate and regimes of equipment use.

Table 1. Functions of an intelligent control system in greenhouse business [5, 11]

Informative Functions	computing and logical functions of informative character
	automatic registration of technological parameters current values and executive mechanisms conditions
	automatic control and fixation of commands
	automatic detection and depiction of operative and inadvertent values of technological parameters
	depiction and registration of a primary reason of inadvertent situations
	sound notification about deviations of the parameters and violations in the technological process
Controlling Functions	automatic control of production systems
	automatic programmed stop (standard and inadvertent) of the system equipment
	change of the current values of technological parameters in the manual mode
	remote control of production systems
	an opportunity of a gradual start of the system while performing commissioning works
Accident-Prevention Functions	automatic protection of the production system by means of control for production and energy equipment
	creation of the necessary technological blocking
	abortion of the commands, which are expected by the algorithm of control
	an opportunity of manual stop of the production system in case of inadvertent situations

At the current stage of the technology development, involvement of the intelligent control systems, which can perform informative, controlling, and accident-prevention functions (Table 1), is critically required in greenhouse business. Efficient introduction of the intelligent control system needs the parameters analysis of the parameters of the environment and production process, which are subjected to the automatic control and regulation, as well as determining of the priorities (Fig. 1).

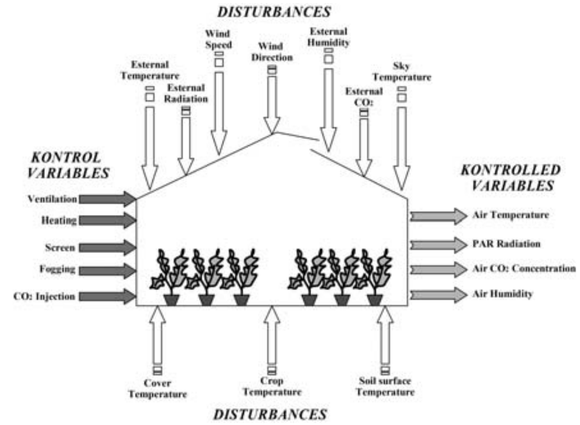

Fig.1. Factors and tools, which create microclimate in a greenhouse [12]

Production of crop products on covered soil is based on the process of photosynthesis, generating of organic substances with participation of carbon dioxide, water and light. Thus, particular attention should be paid to the light regime of plant growing. It is greatly important because the level of solar radiation is characterized both by seasonal and daily inequality, which can be compensated by electric illumination. The process consumes a lot of energy and needs optimization measures. It is partially caused by the seasonal and daily-determined inequality along with the effect of the stochastic component, forced by a change of weather conditions.

To secure the necessary quality and quantity level of plants irradiation, which is expected by agro-technical requirements of cultivation, depending on the variety, type, and vegetation stage, along with natural lighting, it is possible to use artificial light. In some cases, the excess of light can be another problem, requiring performance of the measures and means of plant shading.

The principal technical and energy problem, which is solved in the current research, is to study intelligent control regimes of natural and artificial lighting along with minimization of electric energy use. However, electric energy can be supplied both from external stationary or autonomous electric networks, as well as from renewable sources, e.g. photovoltaic panels.

Peculiarities of lighting regime control

The level of illumination is an important and the least inertial productive parameter. Thus, it requires permanent control and correction. Moreover, the system involvement of artificial lighting of plants considerably increases production costs. Hence, the modes optimization of equipment operation is an obligatory component to support the necessary level of lighting.

The intelligent control system for illumination of greenhouses is used to control the level of lighting and correct it by artificial supplementary lighting, as well as to perform short-term forecast of natural conditions. The forecast serves as a base for creation of an optimized the use strategy of artificial light sources to support the standard level of duration and lighting intensity. A principal share of the standard lighting is secured by means of solar radiation, whereas its deficiency should be compensated by supplementary lighting, produced by artificial light sources.

A change of weather conditions is characterized by two transition processes. The first one corresponds to the period, proceeding deterioration of weather conditions. That period is normally characterized by the excess of solar energy, which is used both for lighting of plants and for accumulation of energy in the storage systems by means of solar photovoltaic panels.

The stage of bad weather conditions is characterized by the insufficient level of solar radiation, which should be compensated by means of artificial supplementary lighting, with the use of energy, accumulated in the storage systems and from external electric networks. However, if the nearest forecast expects fine weather, there is no need for supplementary lighting of plants, because the total level of exposure will be supplied in the following period of favourable weather.

In the system of automatic regulation of the operation equipment mode, which supports greenhouse microclimate, it is needed to use the instruments of short-term weather forecast. Such information can serve to change the algorithm of the level change of lighting and exposure.

Hardware

The Arduino Pro Mini board, supplemented with Wi-Fi or GPS communication module, can be used as the principal hardware of the short-term forecasting system of weather. In case the technical conditions allow placing of a meteorological station immediately near the center of the data processing, the collection of data can be performed by the Arduino Nano, which secures a reliable conductive transfer of the collected information.

Both of the proposed boards are equipped with a microcontroller ATmega 328 and remain on the tune 16 MHz. Thus, operation speed of the developed system is restricted by the carrying capacity of the communication channel and parameters of the chosen sensors. The next important parameter, which influences the choice of sensors, is the level of their energy consumption (it is actual in case of adjusting of the wireless information transfer). Reliability of the sensors and the minimum required maintenance is the last criterion of the choice.

The input parameters for operation of the Fuzzy Logic controller include a current value of temperature, humidity, pressure and the lighting level. To measure the first three parameters, it is recommended to use a meteorological sensor BME 280, and the lighting level can be controlled by means of the sensor GY-302 on the chip BH 1750.

Both sensors are adjusted to the Arduino board by means of the I2C interface. It secures the operation speed up to 3.4 GHz and optimizes the actuating system. Moreover, use of the sensors, with the support of the standardized communication protocols, supplies expansion of the system, e.g. supplementing it with the reserve, doubled, or sample sensors. The chosen sensors transfer the signal in the digital form, reducing the number of errors, increasing the system durability, and simplifying damage detection. According to the certificate, the absorbed current in the mode of measuring does not exceed 834 mA. The sensors also support transition to the sleep mode, securing reduction of the absorbed current up to 0.51 mA. While testing the system, the values of the absorbed current accounted for 612 mA and 0.24 mA respectively.

Fuzzy logic controller

The forecast of weather conditions is a complex technical task, which is based on insufficient and fuzzy information. Under such conditions, it is reasonable to use the fundamentals of the theory of fuzzy sets. They serve as a basis for the best solution of those tasks. Thus, in the present research, the authors used the method of short-term forecast of weather conditions with application of the instruments of Fuzzy Logic.

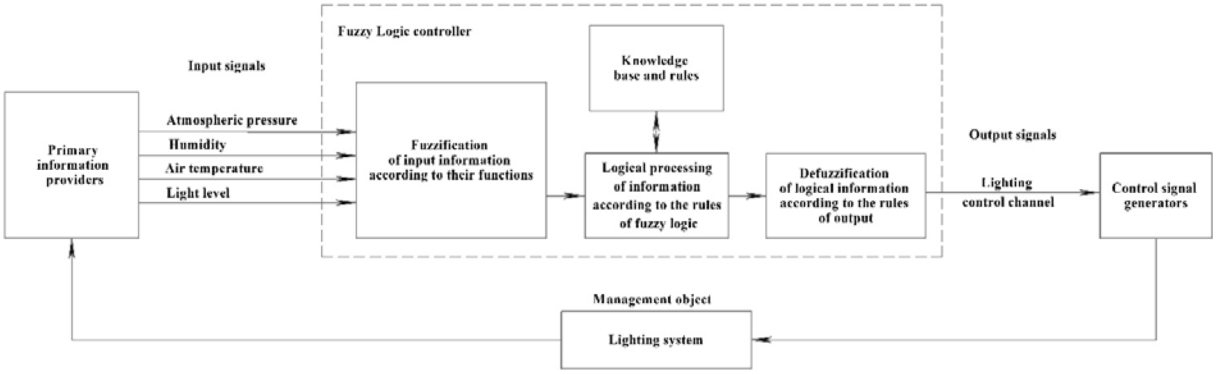

Fig.2. Structural scheme of a Fuzzy Logic controller of the lighting regime in a greenhouse

The essence of the method is revealed in the preliminary phasing of clear input information with its following processing by the methods of algorithms of fuzzy sets with application of the base of rules and knowledge. The information is afterward transformed into a clear form by means of the phasing method. The structural scheme of a Fuzzy Logic controller is presented by the Fig. 2.

A choice of the most important and influential parameters, characterizing the process, is an important stage on the way of the hybrid system creation of control for the operation regime of greenhouse equipment. In the present research, those parameters are represented by the process of a short-term forecast, which largely depends on air pressure, its change, and air humidity.

Those parameters are taken as input ones for the developed Fuzzy Logic controller.

At the next stage, it is also important to choose a range of the change of input parameters and to determine quantity and quality of the terms for input factors. Particularly, for the pressure, the range of the change is set from 900 to 1100 hPa, for relative air humidity – from 0 to 100 %. There are three terms for each parameter, which secure formation of the satisfactory parameters of a short-term weather forecast with a small number of rules. For the parameter of pressure, the set terms include low, medium, and high one; for relative humidity – dry, mid-dry, and humid; for the pressure change – pressure reduction, stable pressure, and increase of pressure.

The terms configuration and their position on the scale of the parameter change, i.e. “Input variable membership functions” and “Output variable membership functions”, are specified at the stage of the controller adjusting with participation of experts.

The output parameter, or the result of operation of the Fuzzy Logic controller, is represented by duration of the necessary supplementary lighting level of plants under the set weather conditions. The range of its change stays within the limits from 0 to 100 % of the total level of exposure. For the parameter of supplementary lighting duration, there are three set terms, i.e. short duration, mid-duration, and long duration.

Fig. 3 demonstrates a work window of the environment of adjusting in the “Variables” mode.

The next stage in development of the controller suggests creation of the base of knowledge and rules, referring to the assessment by weather forecast experts. Fig. 4 presents a work window of the environment of formation of the knowledge base and rules in the “Rule” mode.

This window is used for argumentation of the type of fuzzy inference. The “Center of Area” (Mamdani algorithm) has been chosen for the current case [10, 13-14].

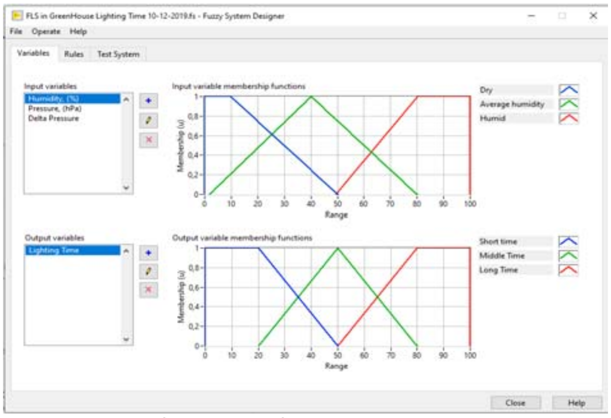

Fig.3. Formation of the terms of input parameters

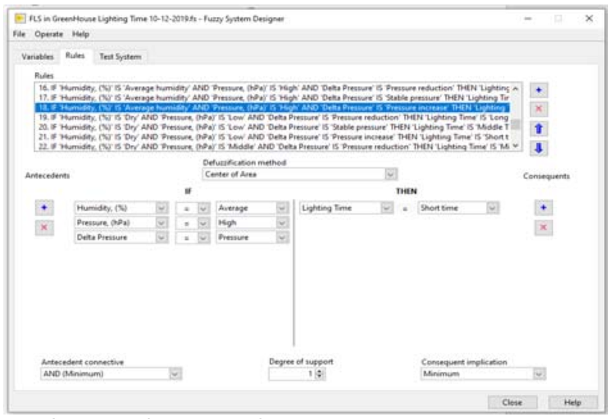

Fig.4. Creation of the base of knowledge and rules

The final adjusting of the Fuzzy Logic controller is performed with application of the work window “Test System” (Fig. 5), basing on the analysis of the surface of responses.

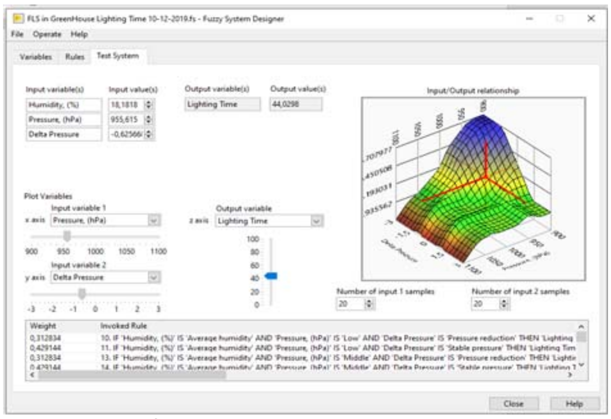

Fig.5. Adjusting of the Fuzzy Logic controller

However, the proposed Fuzzy Logic controller does not consider the reserve of energy in the system of storage and the current value of the photovoltaic panel parameters. Referring to the set priority, the energy of the storage system will be used in the first place. It can cause its critical discharge. Under such conditions, it is recommended to arrange the permission to use energy from the electric network, regardless of the weather forecast, by means of a separate microprocessor commutation device (a device of reserve input). A structural scheme of the system of control for supplementary lighting of plants with the use of solar energy is demonstrated by the Fig. 6.

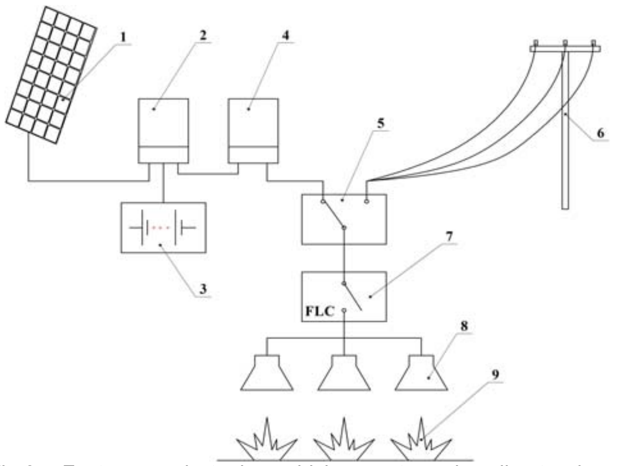

Fig.6. Factors and tools, which create microclimate in a greenhouse [12] Structural scheme of a hybrid system of energy supply for the process of supplementary lighting of plants with the use of solar energy: 1 – a photovoltaic panel; 2 – a charge controller of the storage battery; 3 – a storage battery; 4 – an inverter; 5 – a device of reserve input; 6 – an external electric network; 7 – Fuzzy Logic controller of the lighting system; 8 – a lighting system; 9 – plants.

Conclusions

The article is devoted to examination of the technological processes, completed in a greenhouse. The research points out that accomplishment of the tasks, expected by those processes, requires the best-possible level of the following principal parameters, namely air temperature in the greenhouse; air temperature outside (control); soil temperature in the greenhouse; air humidity in the greenhouse; soil humidity in the greenhouse; concentration of carbon dioxide CO_2 in the greenhouse; concentration of carbon monoxide CO in the greenhouse; level of lighting in the greenhouse; air velocity in the greenhouse; type and the total level of radiation; airspeed outside the greenhouse (control).

The costs for energy supply take a considerable share in the structure of production costs of a covered soil construction. Thus, it is reasonable to develop a system of energy supply for greenhouse business with application of renewable sources of energy referring to the approved structural scheme. Thus, an automatic system of control for the parameters of greenhouse microclimate should be an obligatory element of that energy system. Such control will reduce costs for energy sources and improve ecological compatibility of production.

The system of control for the technological processes, completed at covered soil enterprises, can be secured by using a set of specialized microcontrollers, separate for each technological process. In particular, the researchers propose to make collecting and transfer of the data for the following application in the intelligent control system with hardware and software supply for the Arduino platform. The function of data processing and archiving, as well as visualization of the process parameters needs intelligent processing of data, whereas formation of the signals of control for the technological processes should be performed on the base of LabVIEW software.

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