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Improved Computer-oriented Method for Processing of Measurement Information on Greenhouse Microclimate

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Abstract: *The article presents results of field testing and experimental studies on improvement of the computer-oriented method of aggregation and processing of measurement information on microclimate parameters of industrial greenhouses. The technology was developed and tested in the laboratory. It consists of a hardware component based on Arduino Mega 2560 & Ethernet Shield W5100 and modern sensor devices, a software module based on Simulink Support Package for Arduino Hardware® and a remote database of monitoring results on the ThingSpeak® server. The technology proposed in the article has a modular structure and is adaptive to types and periods of vegetation of cultivated crops. The obtained research results constitute scientific and practical basis for conducting further priority research on implementation of the developed technology into actual production conditions for growing protected crops.*

Keywords: *Computerized technology, Greenhouse, Hardware and software implementation, Monitoring, Microclimate.*

Introduction

At present, a wide range of research is devoted to the problem of developing computerized technology (CT) for studying production processes in agroecosystems. The relevance of research in this subject area is caused by scientific intensity of modern protected vegetable growing and insufficiency of fundamental research in the field of plant physiology and biochemistry [23]. Use of modern sensor, computerized and infocommunication technologies for monitoring and control of greenhouse microclimate parameters [2, 18, 24, 25] allows transition from the phenomenological approach of protected crop cultivation to applying quantitative methods based on the use of simulation models and mathematical procedures [13, 15-17].

Analysis of existing methods and tools of computerized processing of measurement information allowed establishing basic conceptual provisions for designing modern monitoring and control systems for physical and chemical parameters of greenhouse microclimate: implementation of stages of development and research of a model for collection and processing of measurement information using modern standardized hardware and software [14, 20], and main provisions of the technologies Internet of Things, Data Mining and Industry 4.0 [4, 21, 22]; synthesis of structural and algorithmic organization of the CS for monitoring and control of greenhouse microclimate parameters, taking into account the complete list of physical and chemical factors of greenhouse microclimate regulated with measurement control and with the required metrological characteristics [15, 16], namely: T_{soil}, W_{soil}, $T_{solution}$, $pH_{solution}$, T_{air}, W_{air}, V_{air}, E_{area}, C_{CO2}; implementation of the physical prototype of CS for monitoring and control using microprocessor platforms Arduino [1, 19] and advanced sensor technologies [3, 12, 16, 26] accessible and efficient in the field of agriculture.

Thus, the applied problem, the solution of which is the aim of our research, is limited existing research results on efficiency of computerized collecting and processing of measurement information on the dynamics of microclimate parameters in industrial greenhouses. The purpose of the article is to substantiate the improved technology of computerized aggregation and processing of monitoring results of greenhouse microclimate. The technology will allow optimizing technical and economic characteristics of automatic control systems for growing greenhouse crops in order to increase production rate, volume and quality of greenhouse crops.

The subject-matter of the study is the process of computerized aggregation and processing of measurement information about greenhouse microclimate parameters distributed in space and time. The scope of the study is methods and means of increasing the efficiency of computerized systems for monitoring and controlling technological processes in greenhouse vegetable production. The research methods are based on modern achievements in the field of sensory, microprocessor and infocommunication technologies, the theory of information measurement systems, the theory of random processes, as well as on experimental tests of the laboratory prototype of a multichannel computerized measurement system for greenhouse microclimate parameters. 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

The designed prototype for collecting and processing of measurement information on microclimate parameters of industrial greenhouses is a complex of hardware and software for performing measurement control and mathematical processing of observation results in real time, taking into account types and periods of growing greenhouse crops.

Since modes of growing greenhouse crops are dynamic characteristics and monitoring of the main microclimate parameters is carried out with the help of computerized means, the investigated model should be presented in a discrete form, in which time is an independent variable. The input of the prototype receives signals from sensors of the above-stated physical and chemical microclimate parameters, as well as the following factors: type and period of vegetation of greenhouse crops. Therefore, the basic structure of the model can be represented in the following form:

$$Y(i+1) = f\left[Y(i), X(i), Z, P\right]. \qquad (1)$$

The main structural and functional components of the designed technology of computerized monitoring and control of greenhouse microclimate parameters are: a hardware unit (MC of the above stated physical and chemical greenhouse microclimate parameters, microprocessor platform Arduino Mega 2560 with Ethernet W5100 expansion module to collect measurement information, a relay unit for synchronizing the microcontroller and power load, a personal computer with specialized software for local processing of measurement results, Wi-Fi router for network communication with cloud-based server data storage); a software unit (developed specialized software based on Matlab & Simulink®, ThingSpeak IoT analytics®, Arduino IDE); a laboratory sample of an automated greenhouse.

Hardware unit

A set of sensors indicating their metrological characteristics, which are used to implement the hardware part of the CS for collecting and processing of measurement information about microclimate parameters, is presented in Table 1.

Table 1. Characteristics of the sensors used to design the investigated CS

Parameter	**Sensor type**	**Measuring range**	**Main permissible error**	**Reference source**
E_{area}	VT83N1	from 10 to 10^4 lx	±10%	[8]
C_{CO2}	MG811	from 500 to 4000 ppm	±10%	[7]
$pH_{solution}$	E-201	from 0 to 14 rel. un.	±0.2 rel. un.	[5]
T_{air}, T_{soil}, $T_{solution}$	B57891M0103J000	from 15 to 30 °C	±5%	[10]
W_{air}	HIH-4000-003	from 60 to 100 %	±8%	[9]
V_{air}	Rev. P Wind Sensor	from 0 to 2 $m \cdot s^{-1}$	±10 %	[6]
W_{soil}	YL-69 & YL-38	from 10 to100 %	±10%	[11]

The microprocessor unit of the system under investigation is designed based on Arduino Mega 2560 board and the compatible W5100 Ethernet module (see Fig. 1). This module allows synchronizing work of all infrared systems with the developed software in the Simulink® environment and network equipment.

The power load switching unit (process control modules: drip irrigation, ventilation, artificial lighting, heating and humidification, carbon dioxide fertilization and fertilizer dosing) is designed based on Arduino Mega 2560 compatible relay module produced by SONGLE SRD-05VDC, as shown in Fig. 1. This type of relay is controlled by 5 V voltage and can commute the load with parameters up to 10-30 V DC and 10-250 V AC voltage. The hardware component of the system also includes a personal computer (processor – Intel Core i3-4150 CHU @ 3.50 GHz, video adapter – Intel HD Graphics 440, network adapter – Realtek PCle GBE Family Controller, RAM –DDR3 4 GB 1600 MHz Hynix Semiconductor) and Wi-Fi router Tenda N301 (802.11 b/g/n, 300 Mbps).

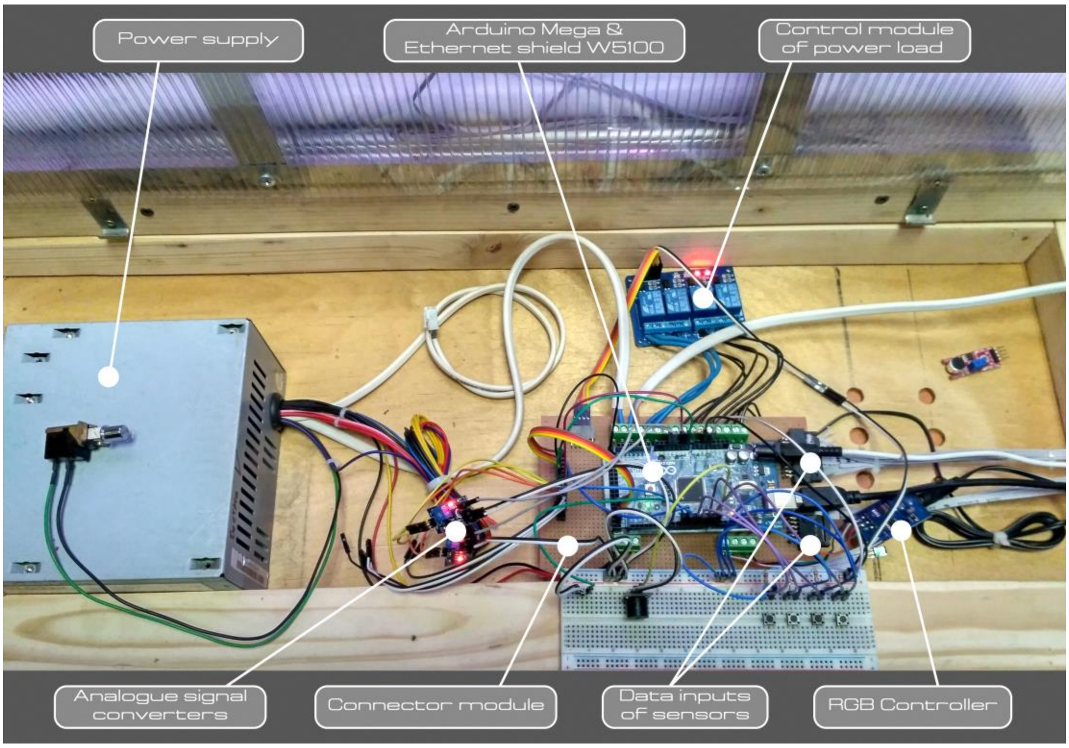


Fig. 1 View of analog and microprocessor components

Software component

Approaches to investigating the technology for processing measurement information on dynamics of greenhouse microclimate parameters are based on modern advances in the field of sensor, microprocessor and infocommunication devices, as well as on basic provisions of mathematical, physical and simulation modeling of multichannel information and measurement systems. To implement the main stages of development and research of the technology stated above we used the following software products:

- development and testing procedures of basic software of the CS were performed in Arduino IDE environment;
- study of the model for collecting and processing of measurement information was performed in Simulink® R2016a simulation environment using Simulink Support Package for Arduino Hardware;
- remote monitoring and accumulation of a database of monitored parameters was performed with ThingSpeak® IoT analytics service, which supports synchronization at the software level with Matlab & Simulink®.

Laboratory sample of an automated greenhouse

The appearance of the laboratory sample is shown in Fig. 2. The developed physical prototype takes into account the geometric similarity condition with real industrial greenhouses (h:a:b is 1:1:0.6). The dimensions of the physical prototype of a greenhouse are the following: h = 1.5 m, a = 1.5 m, b = 0.9 m. The greenhouse type is a vegetable one, year-round use; greenhouse material is polycarbonate.

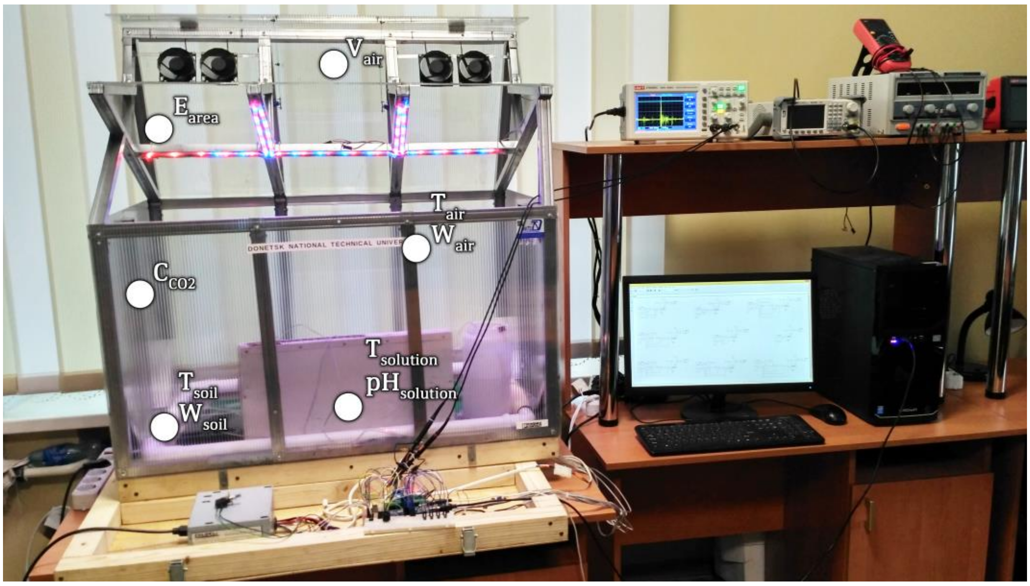


Fig. 2 View of the experimental unit

The above set of hardware and software meets the conditions of necessity and sufficiency of development and investigation of CT for processing of measurement information on physical and chemical parameters of greenhouse microclimate.

Method of experimental research

Experimental research was carried out on the basis of an algorithm, the block diagram of which is shown in Fig. 3.

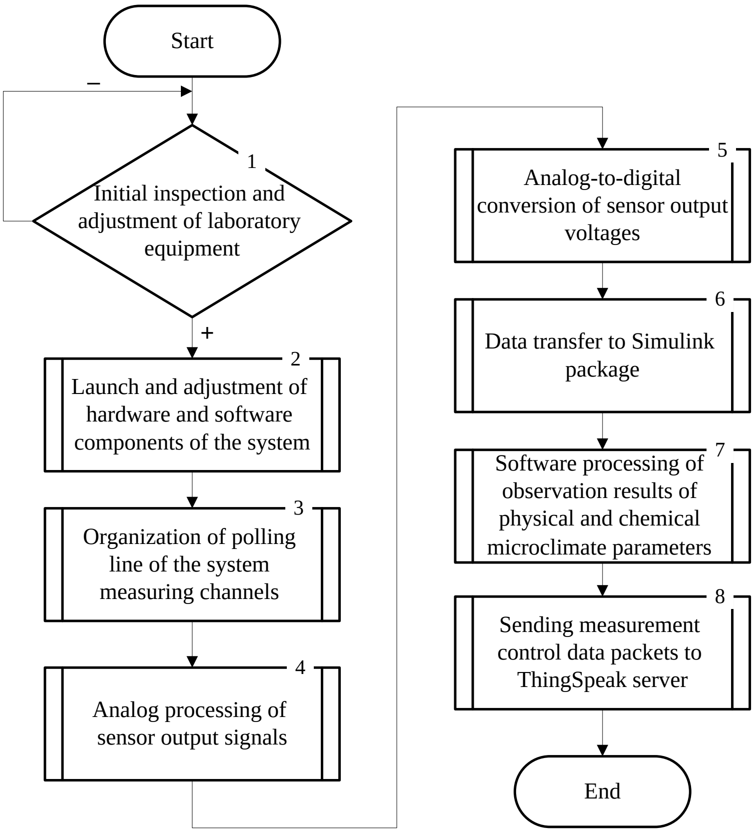


Fig. 3 Block diagram of the algorithm for experimental studies of CT

Results and discussion

As a result of our research, we developed a structural diagram of the CS for monitoring and control of greenhouse microclimate parameters (see Fig. 4). This diagram has a modular structure and performs the following functions:

- collecting primary measurement information from MC: T_{soil}, W_{soil}, $T_{solution}$, $pH_{solution}$, T_{air}, W_{air}, V_{air}, E_{area}, C_{CO2};
- analog processing of sensor output signals of physical and chemical parameters with subsequent conversion to a digital form;
- averaging the monitoring results and calculating values of digital signals in units of physical and chemical quantities;
- local indication of the monitoring results and their accumulation in a database on a remote server;
- generating control signals by modules for maintaining technological processes of drip irrigation, ventilation, artificial lighting, heating and air humidifying, carbon dioxide fertilization and fertilizer dosing.

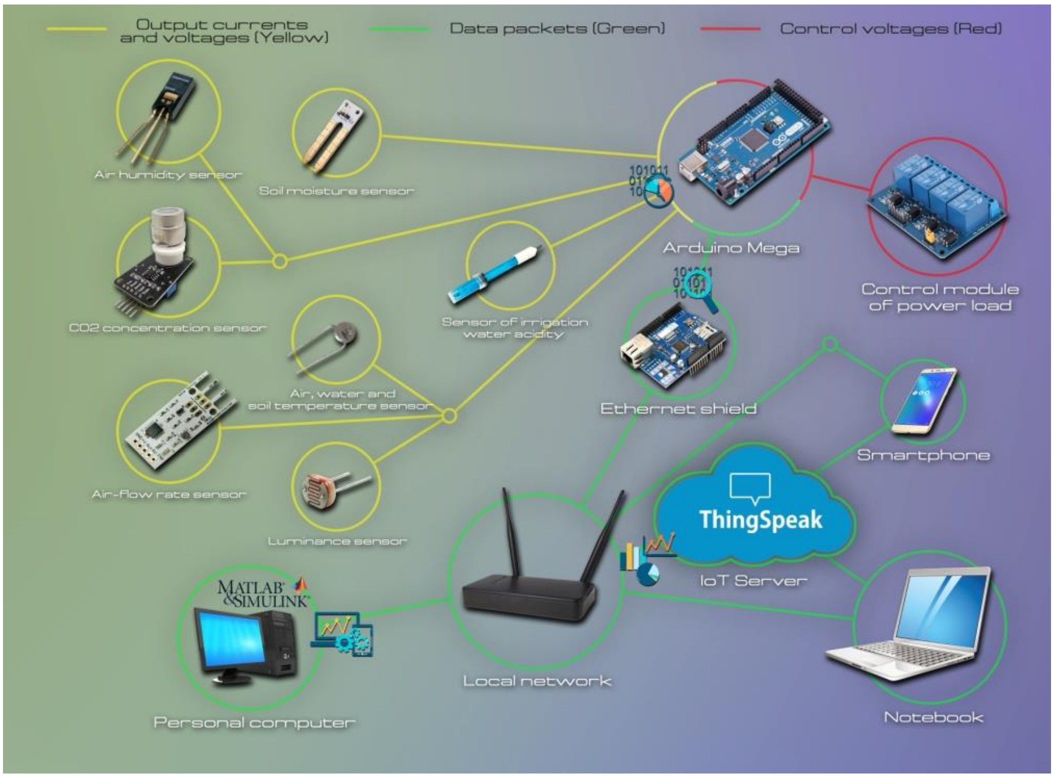
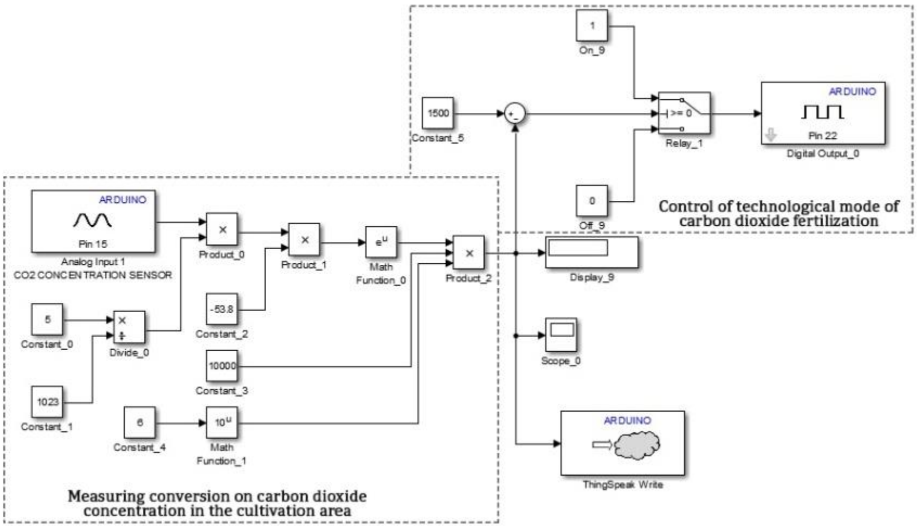
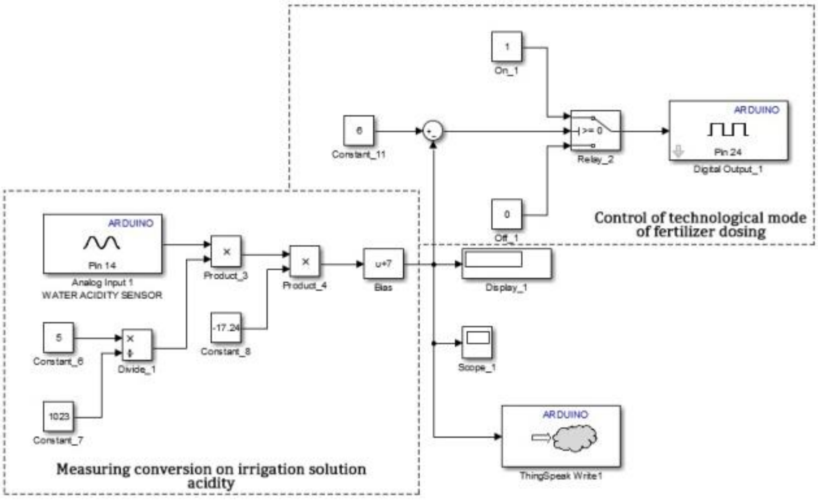


Fig. 4 Structural diagram of the developed CS

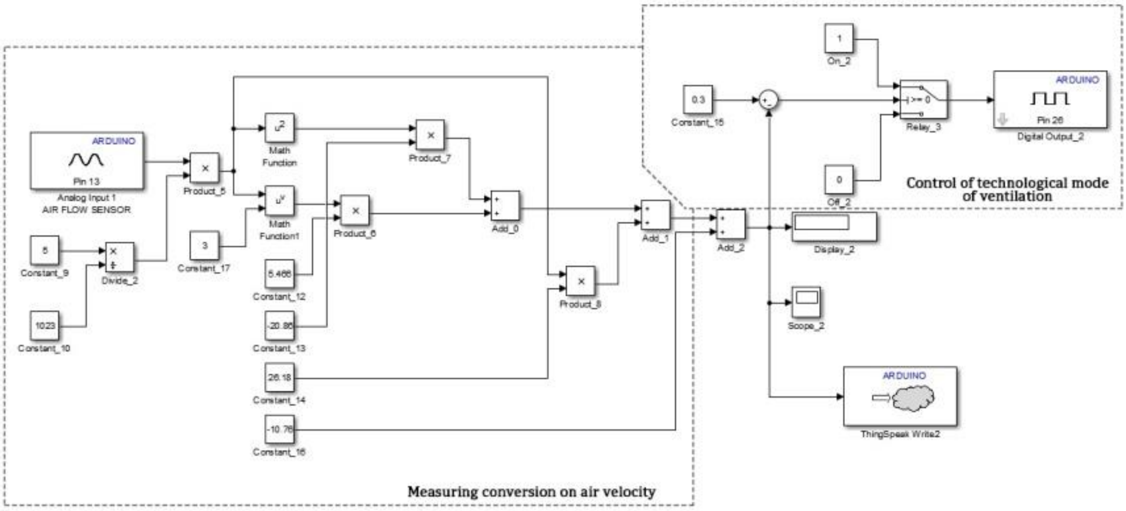
The developed software component of the system (see Fig. 5) is universal and is able to work with different numbers of MCs. This software has the function of adapting basic technological modes of growing crops to their types and periods of vegetation. This functionality is carried out with the possibility of varying the threshold values of triggering of the embedded control components in the Simulink® simulation environment (see Fig. 5, *Constant_5*, *Constant_11*, *Constant_15*, *Constant_22*, *Constant_29*, *Constant_33*, *Constant_37*, *Constant_44*, *Constant_51*).



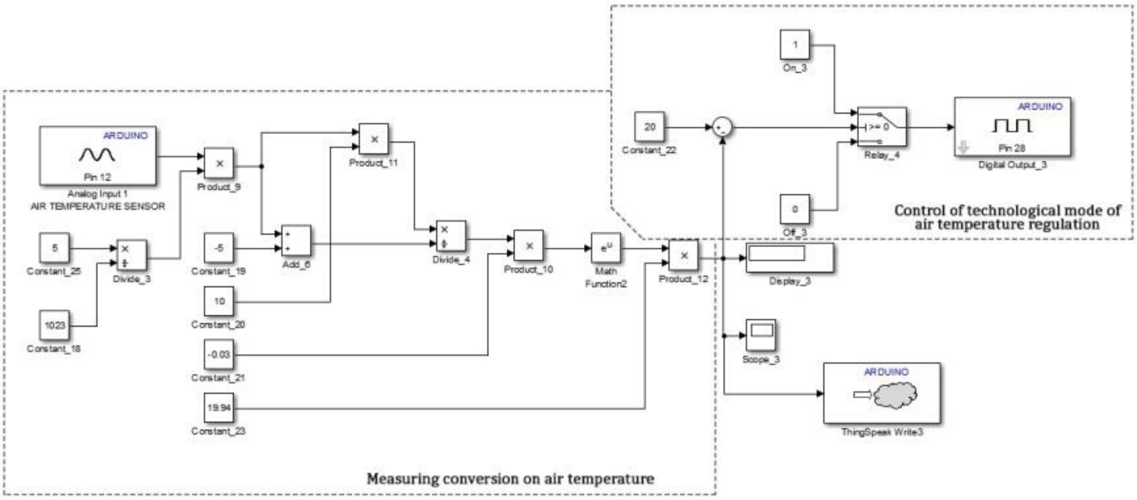
(a) C_{CO2}



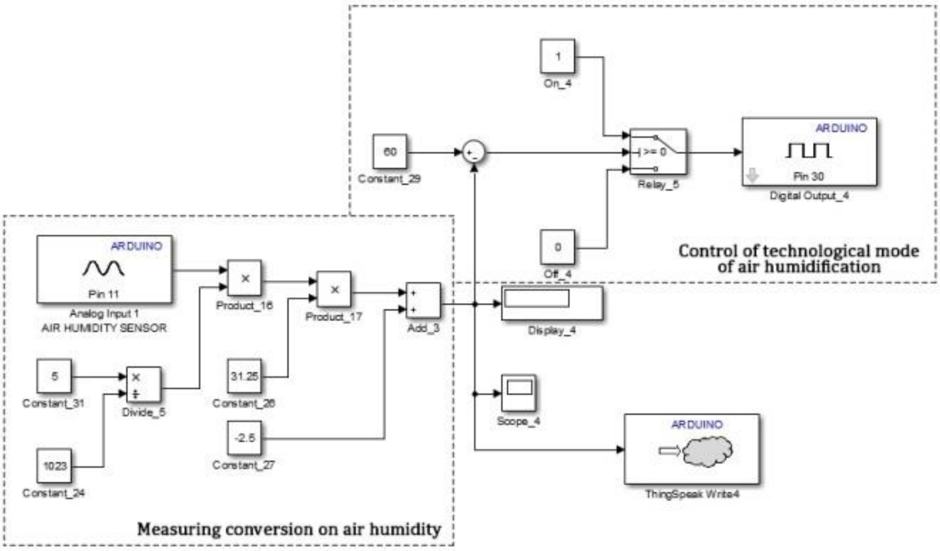
(b) $pH_{solution}$



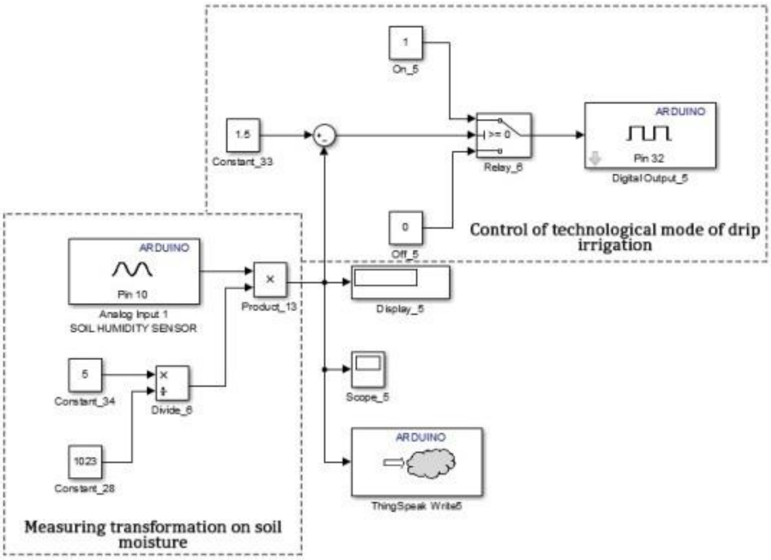
(c) V_{air}



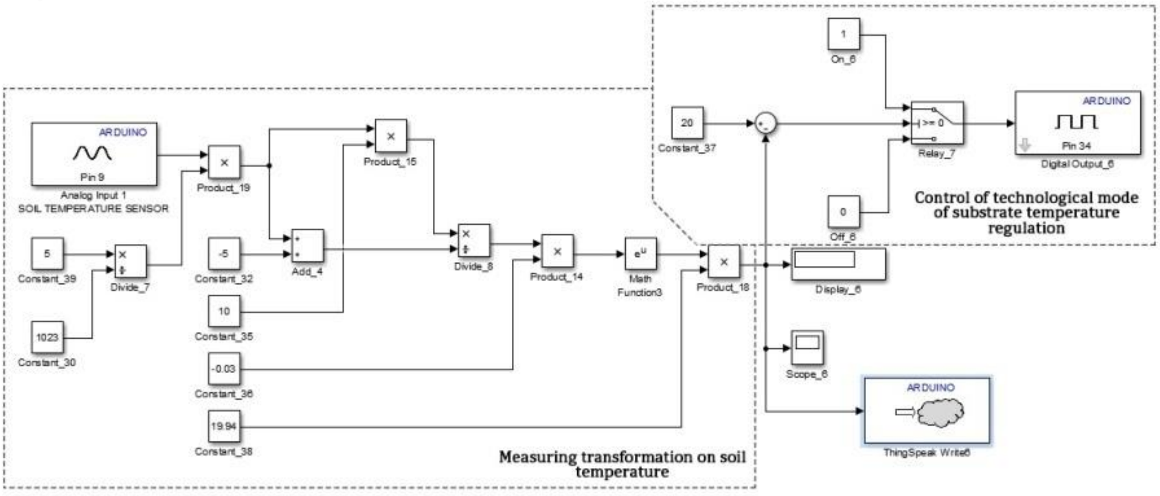
(d) T_{air}



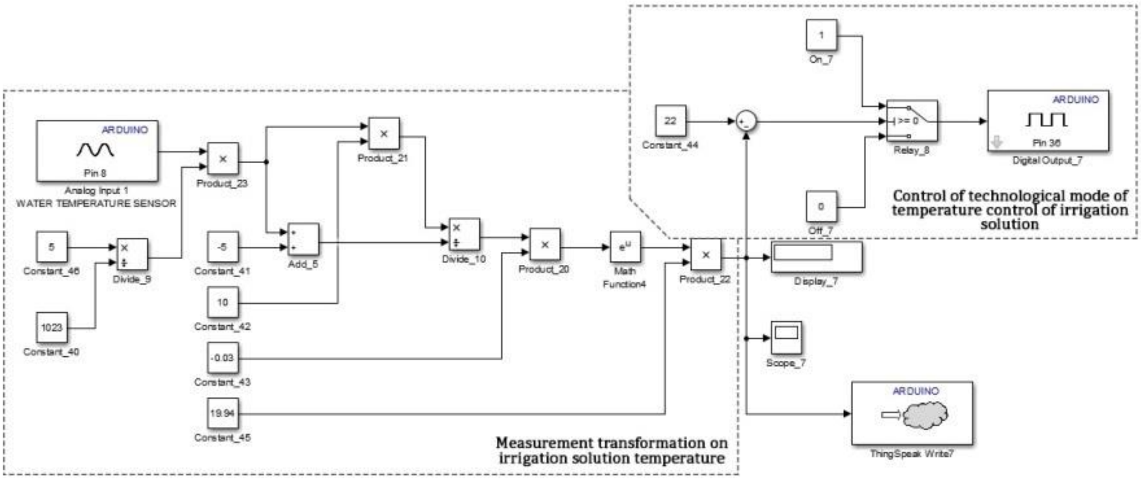
(e) W_{air}



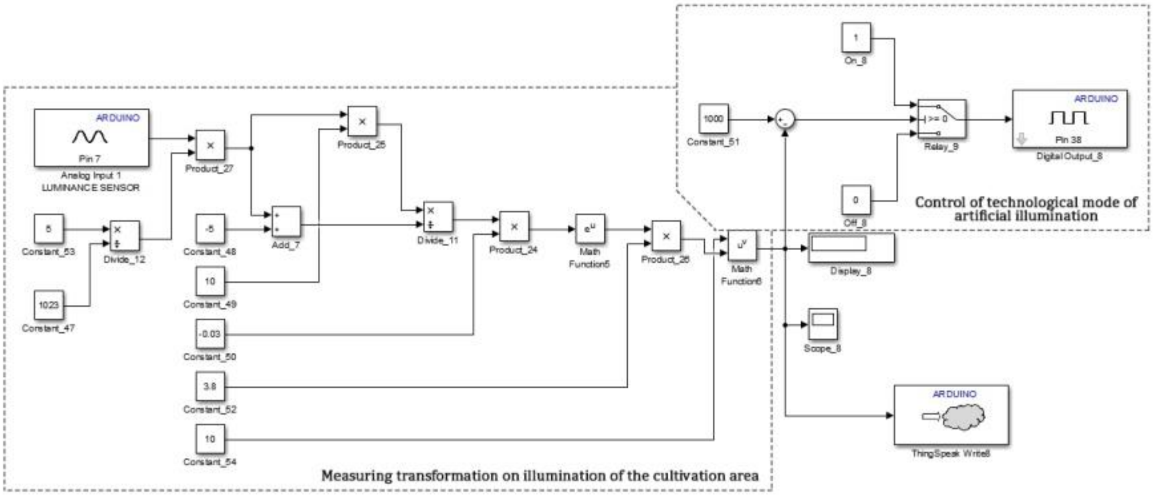
(f) W_{soil}



(g) T_{soil}



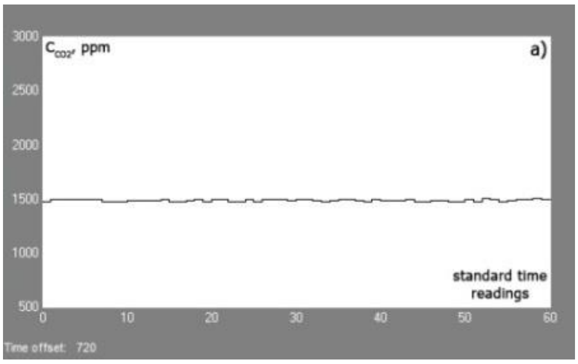
(h) $T_{solution}$



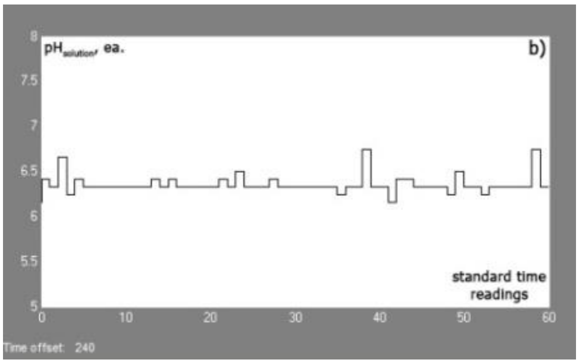
(i) E_{area}

Fig. 5 Interface of the CS software component

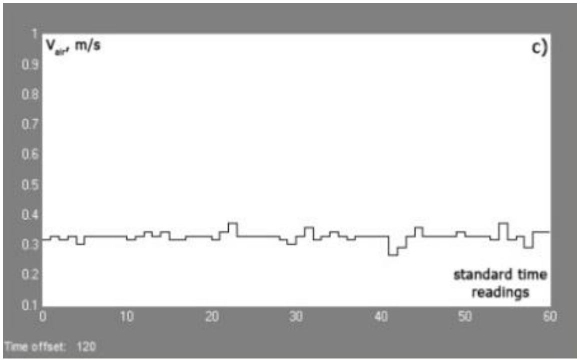
The results of laboratory trials of the developed technology for processing measurement information on greenhouse microclimate are shown in Fig. 6, the sampling spacing in the simulation is 30 seconds.



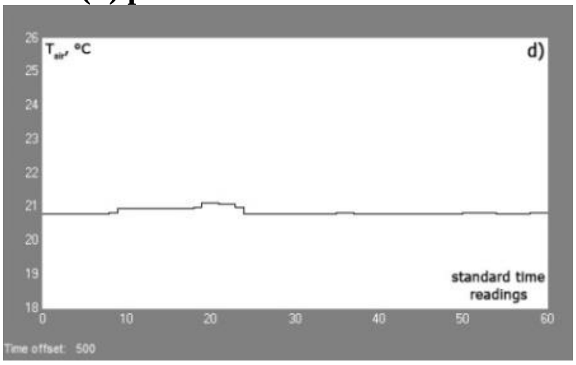
(a) $C_{CO2}=1500\pm10$ ppm



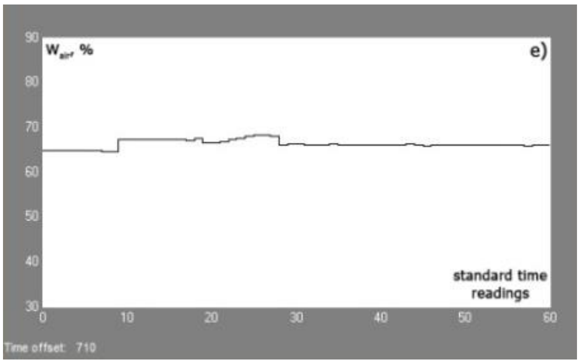
(b) $pH_{solution}=6.48\pm0.25$ rel. un.



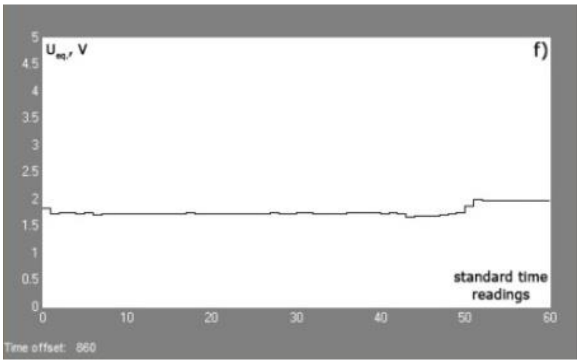
(c) $V_{air}=0.32\pm0.05$ m·s^{-1}



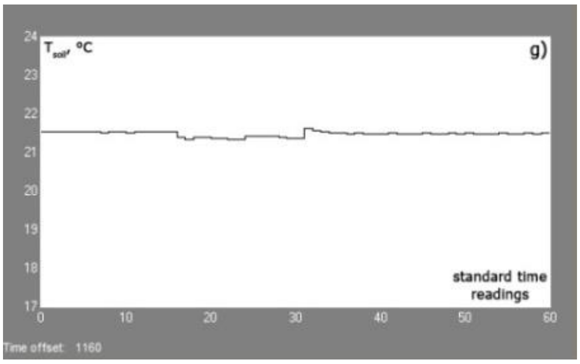
(d) $T_{air}=20.8\pm0.5$ °C



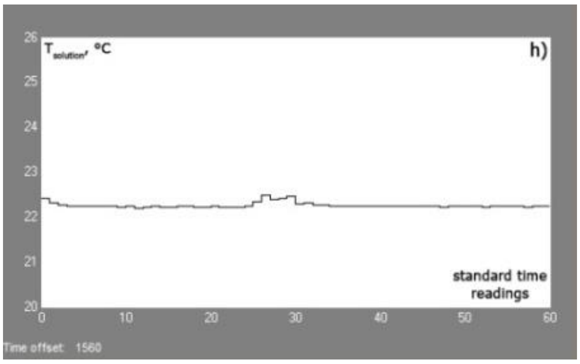
(e) $W_{air}=65\pm3$ %



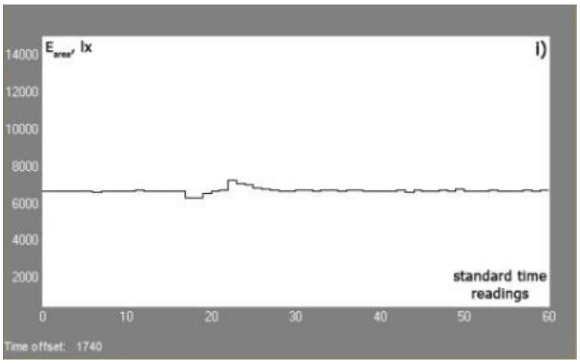
(f) $U_{eq.}=f(W_{soil})=1.8\pm0.1$ V



(g) $T_{soil}=21.5\pm0.5$ °C



(h) $T_{solution}=22.3\pm0.5$ °C

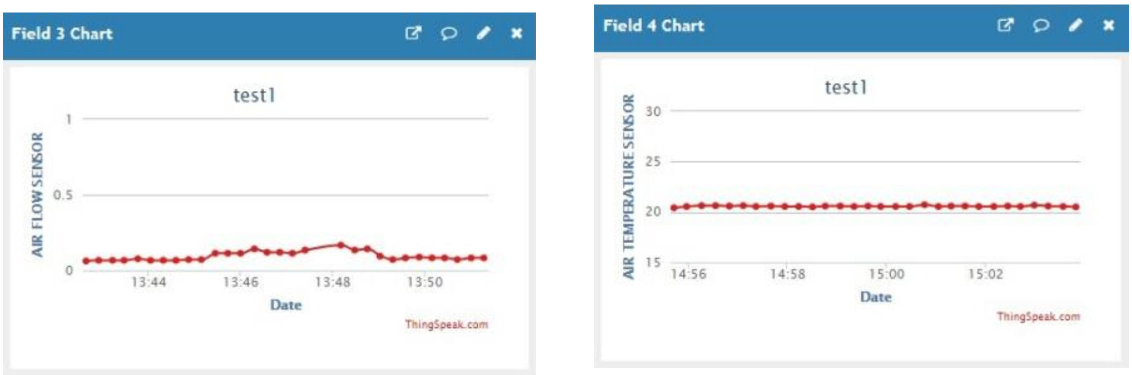


(i) E_{area}=6850±50 lx

Fig. 6 Results of laboratory trials of the implemented technology

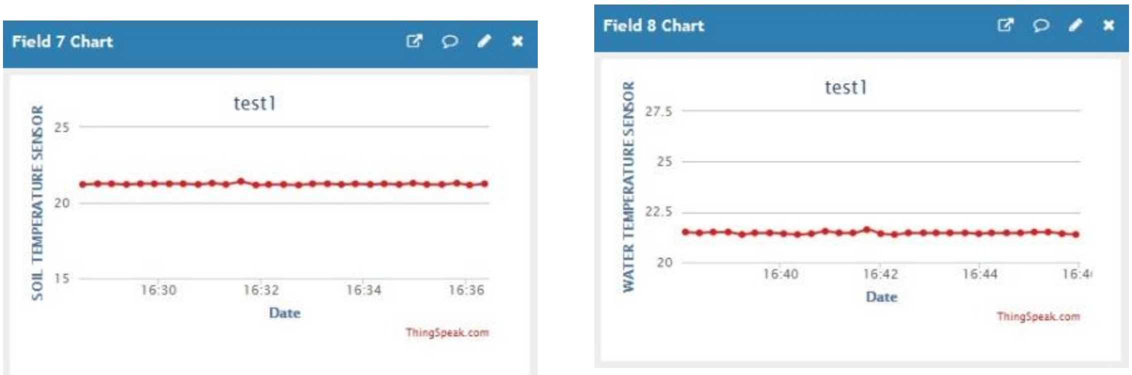
The designed software allows recording measurement results to a remote server by using standard components from the Simulink Support Package for Arduino Hardware® (see Fig. 5, *ThingSpeak Write –ThingSpeak Write_8*). The results of remote monitoring of physical and chemical parameters using the ThingSpeak® service are shown in Fig. 7.

(a) C_{CO2} **(b) $pH_{solution}$**



(c) V_{air} **(d) T_{air}**

(e) W_{air} **(f) $U_{eq.}=f(W_{soil})$**



(g) T_{soil} **(h) $T_{solution}$**

(i) E_{area}

Fig. 7 Results of remote monitoring of microclimate parameters

Analysis of the obtained simulation results confirms the primary possibility of using the proposed technology in the real conditions of protected crops cultivation.

The results obtained in this research are the scientific and practical basis for further priority research on development of methods and means to increase information value of computerized monitoring and control of microclimate parameters of industrial greenhouse complexes.

The developed computer-oriented method can be used as a tool for research on optimization of structural and algorithmic organization of computerized monitoring and control systems of greenhouse microclimate parameters. The future work would be to use more statistical data for the development of prediction models, which will be analyzed in the cloud side using IoT and Data Mining technologies. The researches on evaluation of energy and economic performance of the system is necessary to perform in the near future.

Conclusion

The research results obtained in this study are devoted to the solution of the topical scientific and applied problem of efficiency increasing of production processes of growing crops in industrial greenhouses. Having conducted the research we improved the computer-oriented method of collecting and processing measurement information on a complex of regulated parameters of greenhouse microclimate.

The main scientific and practical results of this work are: substantiation of the set of requirements for hardware and software components of computerized monitoring and control system for greenhouse microclimate; development and research of the model of aggregation and processing of measurement information on the dynamics of microclimate parameters using Matlab & Simulink®; implementation and laboratory trials of the technology of remote aggregation of monitoring results using the ThingSpeak® service.

The analysis of the obtained results of experimental studies of the proposed computer-oriented method confirmed the possibility of its application in the real conditions of protected crop cultivation.

The main promising areas of research in order to improve the efficiency of computerized monitoring and control over greenhouse microclimate are: accumulation of a statistical sampling database of observation results of the dynamics of physicochemical microclimate parameters with their subsequent regression analysis, taking into account types and periods of crop vegetation; optimization of the structural and algorithmic organization of computerized monitoring and control systems for microclimate parameters with their subsequent introduction into real operating conditions; development of scientific and practical approaches to calculation of the complex influence of greenhouse microclimate parameters on the quality indicators of growing crops in greenhouses.

Nomenclatures and abbreviations

T_{soi} – soil temperature in the root layer, °C;
W_{soil} – soil humidity in the root layer, %;
$T_{solution}$ – solution temperature at watering, °C;
$pH_{solution}$ – solution acidity during irrigation, rel. units;
T_{air} – air temperature in the cultivation area, °C;
W_{air} – air humidity in the cultivation area, %;
V_{air} – air velocity in the cultivation area, $m \cdot s^{-1}$;
E_{area} – effective illumination of the cultivation area, lx;
C_{CO2} – concentration of carbon dioxide in the cultivation area, ppm;
$U_{eq.}$ – equivalent output voltage of soil moisture sensor, V;
Y – state vector of the prototype;
X – vector of controlled microclimate parameters;
Z – type of cultivated crops;
P – period of crop vegetation;
i – sample spacing of the prototype;
h – height of the greenhouse physical prototype;
a – length of the base of the greenhouse physical prototype;

b – width of the base of the greenhouse physical prototype;
IoT – Internet of Things;
MC – measuring channel;
CS – computerized system;
CT – computerized technology;
RAM – random access memory.

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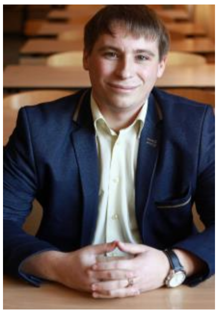

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