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Microclimate Monitoring System for a Home Greenhouse as Part of ESP32

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Abstract

This article is related to designing a home greenhouse monitoring system using WSN and IoT technologies. Wireless Sensor Network (WSN) and Internet of Things (IoT) technology are the most advanced IT technologies and provide fast and distributed data collection and monitoring in various industries and widespread access to use. The developed “Microclimate GH” system allows for accurate measurements and monitoring of the microclimate of the home mini-greenhouse in real time through a mobile application. Monitoring data can be stored in the cloud and displayed in the form of reports and graphs and will be available for analysis at any time. Three important processes are being implemented: cooling, watering and lighting. The results of graphs and histograms analysis help the user to timely and accurately identify microclimate violations and take the necessary measures.

The proposed system is implemented on the basis of the ESP32 microcontroller with built-in Wi-Fi and Bluetooth modules, which has a significant advantage over the analogue of the ESP8266. The developed system compares favourably with its other prototypes by its accessibility to a wide user, good communication quality, good design and construction. The economic effect of using the proposed technology amounted to 10,000 tenge, the payback period is 4 seasons.

Keyword:*home mini-greenhouse, monitoring, IoT, WSN, ESP32, ESP8266*

I. INTRODUCTION

In [1], researchers developed monitoring and control parameters in a greenhouse. In [2–5], an automatic control system was used for the microclimate of plant growth in a greenhouse. In articles [6–9], developers developed energy use models and cost-energy analysis in greenhouse vegetable production. New technologies for controlling ambient temperature using cooling devices were applied in [10, 11, 12]. At present, heat pumps are used to improve the production of vegetables in greenhouses, which are the main units for cooling systems in greenhouses. In [13], a model for predictive control of heating, ventilation, air

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conditioning for two greenhouses was developed. Researchers in [14] developed a physical model of energy consumption of greenhouses.

A new SVMr algorithm for predicting the daily temperature for heating or air conditioning systems was presented in [15, 16]. A new control system was proposed consisting of a module for minimizing energy costs and a module for implementing a specific input using existing equipment [16]. In [17], an algorithm and program for a neural network in a greenhouse were developed. In [18], an artificial neural network was developed for modeling a greenhouse in a thermal environment.

This article is about designing a home greenhouse monitoring system using WSN and IoT technologies.

II. OPERATING PRINCIPAL

II. I System architecture and technological equipment

The system architecture has three levels (Figure 1): First level is an application level. Object management operations and display reports using interface tools are performed at this level (control buttons, charts, and histograms). Second level is a level of processing and data transfer. Data exchange operations between devices are implemented at this level. ESP32 microcontrollers with built-in Wi-Fi and Bluetooth modules are used. The first module ESP32 (1) acts as a transmitter - receives a signal from the sensors of the control object and transmits a signal to the second module ESP32 (2), which plays the receiver role. The ESP32 (1) and ESP32 (2) modules perform two-way data exchange, providing measurement and control operations, interacting with the third level. Third level is the object level. The greenhouse has greenhouse environmental sensors.

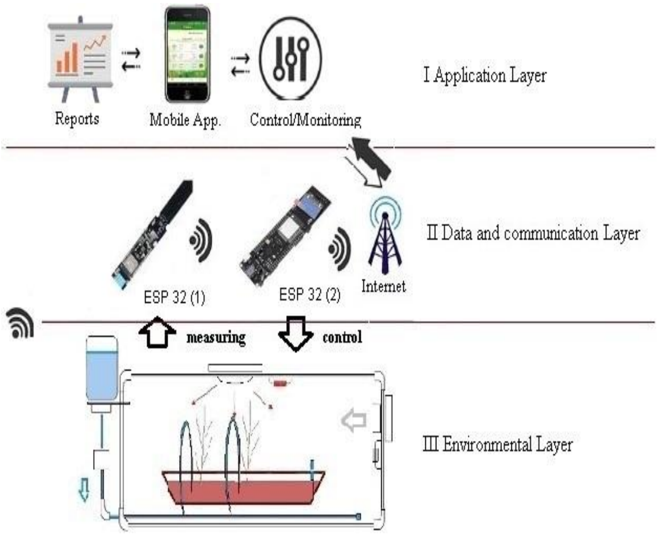

Fig 1. System architecture

Spring unheated greenhouse is considered. Figure 2 shows the technological scheme of the mini-greenhouse. The system implements three technological processes (TP): cooling, watering and lighting.

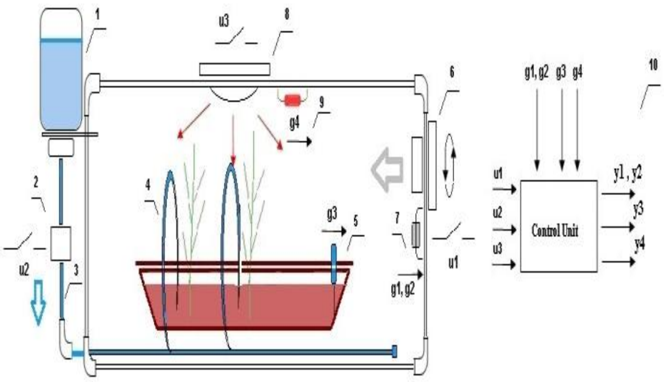

Fig 2. Technological circuit of Greenhouse work

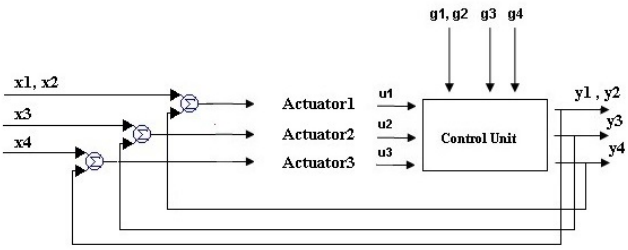

Fig 3. Control unit

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The system parameters are set, respectively, air temperature *x*1, air humidity *x*2, soil moisture *x*3, and lighting intensity *x*4.

The control unit uses the feedback control principle (with deviation) (Figure 3). The accumulator register, which is part of the control unit, compares the corresponding master action *x*(*i*) (where *i* = 14) with the corresponding output signal *y*(*i*) (where *i* = 14), and generates the control action *u*(*k*) (where *k* = 13), which is fed to the input of the corresponding actuating mechanism (AM): fan, irrigation valve and searchlight.

The drip irrigation system works as follows. The tank is filled with water (1). The control unit (CU) (10) controls the water supply (control action *u*2), that it opens / closes the water valve (2) by turning on / off the controller relay. When the valve opens, water flows down (blue arrow), passing through the main pipeline (3) and the dropper (4), and water the plant in the pot (brown vessel). Information on soil moisture *g3* is measured by a moisture sensor (5) and transmitted to the controller, the control unit is received.

The cooling system is described as follows. The control unit controls the air supply to the greenhouse, forming the control action *u1*, by turning on / off the fan (6) through the relay. Air supply is indicated by a gray arrow. The temperature sensor (7) measures the temperature *g1* and the relative air humidity of the greenhouse *g2* and transmits data to the control unit.

The lighting system controls the light mode of the greenhouse. The control unit generates a control action *u3*, which turns on / off the searchlight (8) via the controller relay. Lighting intensity data *g3* is measured by a light sensor (9) and are transmitted to the control unit.

Figure 4 shows the structure of the control unit (10), which consists of a microcontroller-transmitter and a microcontroller-receiver. The ESP32 (1) transmitter receives signals *g1*, *g2*, *g3*, *g4* and transmits to the ESP32 (2) receiver via a WiFi or Bluetooth network. The receiver performs data processing based on control commands received from a mobile application or web interface and transmits control signals *u1*, *u2*, *u3* to the corresponding AM.

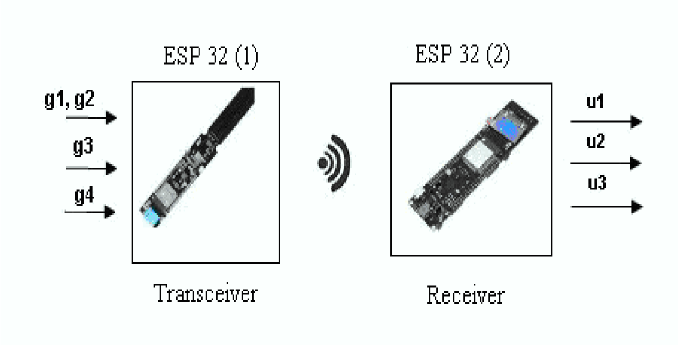

Fig 4. Transceiver and Receiver

Figure 5 shows the electrical connection of the signal sensors as part of the ESP32 transmitter (1). The circuit consists of an ESP32 microcontroller, a CP2104 module WiFi& Bluetooth, a Soil sensor, a DHT11 temperature and humidity sensor, and an LM393 based photo sensor.

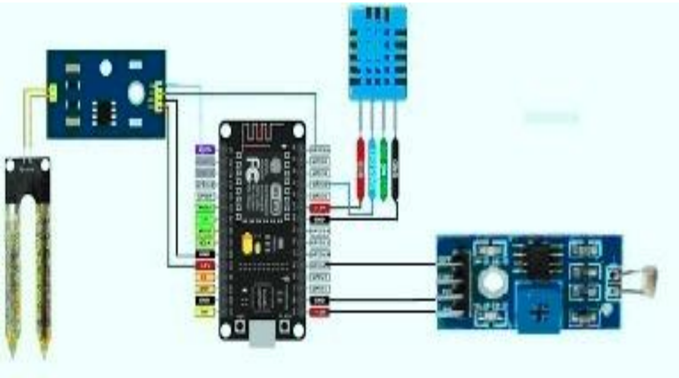

Fig 5. Electrical connection circuit of measure sensors in Transceiver

Figure 6 shows the electrical connection diagram of actuators to the ESP32 receiver (2). The diagram consists of an ESP32 microcontroller, a CP2104 WiFi& Bluetooth module, a board of 4 relays, actuators: Dospel fan, solenoid valve from the washing machine and LED Led Flood Light Outdoor searchlight.

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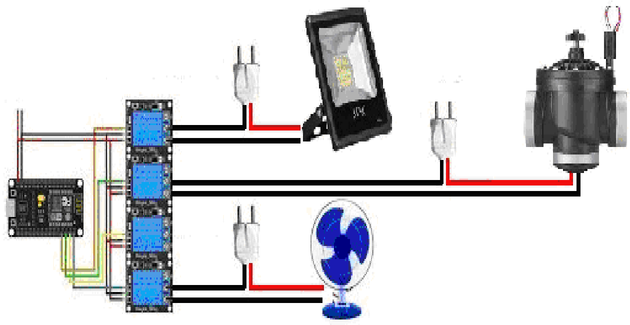

Fig 6. Electrical connection circuit of actuators in Receiver

Figure 7 shows the system configuration parameters in program code. The program uses libraries for communication with a WiFi network, WiFiClient, with a Blynk mobile phone, WidgetRTC, with a DHT sensor, and a TimeLib library. Network name is STAR.

```
/* Comment this out to disable prints and save space */
#define BLYNK_PRINT Serial


#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
#include <TimeLib.h>
#include <WidgetRTC.h>
#include <DHT.h>

// You should get Auth Token in the Blynk App.
// Go to the Project Settings (nut icon).
char auth[] = "r1GQnTwlyF5M3sQ5CStocZopjsZGhPZB";

// Your WiFi credentials.
// Set password to "" for open networks.
char ssid[] = "STAR";
char pass[] = "KZ141095";


#define DHTPIN 26
#define SOILPIN 25
#define DHTTYPE DHT11


DHT dht(DHTPIN, DHTTYPE);

BlynkTimer timer;

// This function sends Arduino's up time every second to Virtual Pin (5).
// In the app, Widget's reading frequency should be set to PUSH. This means
// that you define how often to send data to Blynk App.
void sendSensor()
```

Fig 7. Parameters of system configuration in program code

II. II System and equipment specifications

Table 1 provides a list and characteristics of equipment, components and programs used in the greenhouse implementation.

Table 1. Technological equipment, materials and programs

Equipment and materials	Model	Specifications
Greenhouse and components		
Frame	Material – PolyVinylChloride pipes (16 m)	Dimensions: 1,5 m x 1,4 m x 0,8 m Pipe diameter 32 PN.
Pot	Material – plastics (1 pcs)	Dimensions: 120 x 90 x 50 cm.
Ground (biohumus)	Ground universal (1 pcs)	Volume - 25 kg, shelf life - 5 years.
Communication device		
Mobile phone	Samsung (1 pcs)	Model SM - T239. Operating system - Android 4.4.4
Control and communication device with a mobile phone		
Microcontroller + Transmitter	ESP32 WiFi&Bluetooth CP2104 Soil DHT11 Soil Temperature Humidity Sensor (1 pcs)	ESP32 Bluetooth WiFi development board, support Nodumcu / Arduino DHT11 temperature and humidity sensor CP2104

		communication chip USB TO TTL Micro USB port Soil probe (long) soil temperature and humidity detection module LM393 based photosensor
Microcontroller + Receiver	ESP 32 WiFi + Bluetooth + battery (1 pcs)	ESP32 Bluetooth WiFi development board, support Nodumcu / Arduino CP2104 communication chip USB TO TTL Micro USB port 18650 Lithium Battery Holder Powered (Battery is not included)
Programming support environment of MK	Arduino IDE (1 pcs)	version 1.8.10
Mobile Application	Blynk (1 pcs)	version 2.27.6

Development Environment		
Actuating mechanism (AM)		
Air-cooling	Fan Dospel (1 pcs)	220 V, 15 W, diameter 100 mm, flow rate 100 cubic meters / hour.
Lighting	Searchlight street (1 pcs) Led Flood Light Outdoor 220 V, 80 W, lighting angle	120º, 2700 lm, white color. Service life of 50,000 hours.
Magnetic valve	From the washing machine	220 V, 8 W, NZ contact
Drip watering system		
Hydraulic system	Tank 1 l (1 pc), PVC pipe diameter 16 PN, length 3 m (1 pc), droppers diameter 4 mm, length 80 cm, holes 0.8-1 mm every 15 cm. (8 pcs), components (fittings, tees, plugs).	
Components	Electrical wires, clamps, contacts, trellis, lasso for garter, etc.	

The system uses low-cost, low-power microcontrollers, series ESP32 with low energy usage. They are a system on a chip with integrated Wi-Fi and Bluetooth controllers and antennas based on the TensilicaXtensaLX6 microcontroller. These boards operate in environmental conditions from -40 ... to +125 ° C, at a frequency of 2.4 GHz, with a

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data transfer rate of 150 MB, with a maximum transmit power of 19.5 dB.

The ESP32 series are distinct from the ESP8266 series with many additional features (table 2, [8]). It should be noted that the main drawback of the ESP8266 board is that for each connected sensor an additional ESP8266 microcontroller is required (it causes inconvenience of installation and increases the price), although a huge number of IoT home automation projects have been implemented on the basis of ESP8266 to date.

Table 2. Comparative characteristics of the ESP32 and ESP8266 chips:

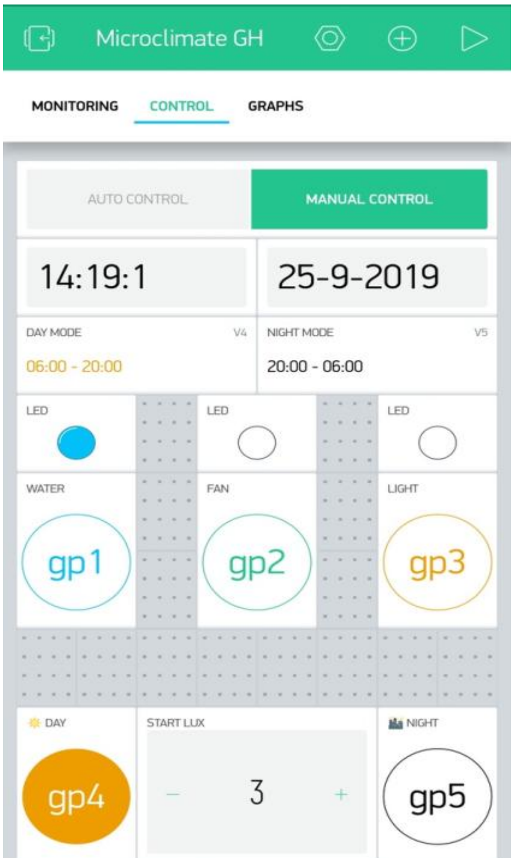
ESP32	ESP8266
Ethernet MAC Interface, GPIOs für 10 Touch-Sensoren, Temperatur-Sensor (on-chip), Remote-Controller-Funktionalität, Hall-Sensor, Digital-to-Analog Converter (DAC), CAN 2.0	Not supported
Analog to digital converter (ADC): 16 Channels with 12-Bit SAR-ADC with low noise amplifier (Low-Noise Amplifier, LNA)	10-bit ADC, without LNA
Two I2C-interfaces	One I2C-interface
16 Channels for wideband frequency modulation	8 Channels for wideband frequency modulation
GPIOs (General-Purpose Input/Output, general purpose input / output interface): 36	GPIOs: 17
4 SPI-interfaces with Quad-SPI and with a maximum frequency of 80 MHz	3 SPI-interfaces with Quad-SPI and with a maximum frequency of 80 MHz

III. RESULTS AND DISCUSSION

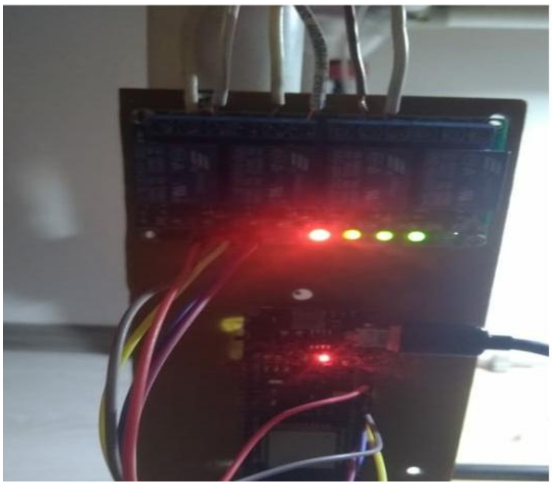
The proposed system can be used as an IoT device for monitoring important parameters of the greenhouse – temperature and air humidity, soil moisture and lighting (Figure 7). The project is implemented on the basis of an affordable and inexpensive, multi-functional ESP32 board, which has a significant advantage over the ESP8266 analogue. The specifixations of this board make it possible to provide high-quality control and management in wide climate conditions (temperature -40 ... + 125°C) with a data transfer rate of 150 MB/s, with a stable UDP bandwidth of 135 Mb/s with low power consumption. Monitoring and manual control of the microclimate state is carried out using a mobile device and through the user's web application (Figure 8).

Figures 9 and 10 show the results of monitoring processes in the greenhouse during the growing season (60 days). The first graph shows the processes graphs (time series) taken from the readings of sensors g1, g2, g3, g4. The second figure shows processes graphs after the operation of smoothing data by the Moving Average method. The purpose of this operation is to identify and statistical assess the main trends in the development of the studied process and deviations from it. Table 3 shows the parameters of growing tomato in a greenhouse and the average values of adjustable values y(i) for this case. It is not difficult for the user to assess the state of the microclimate based on these average readings of the microclimate. According to the last table, it is necessary to make recommendations for growing vegetables in the greenhouse. The results show that the regulated values that determine the microclimate lie in the optimum region and correspond to the cultivation rate.

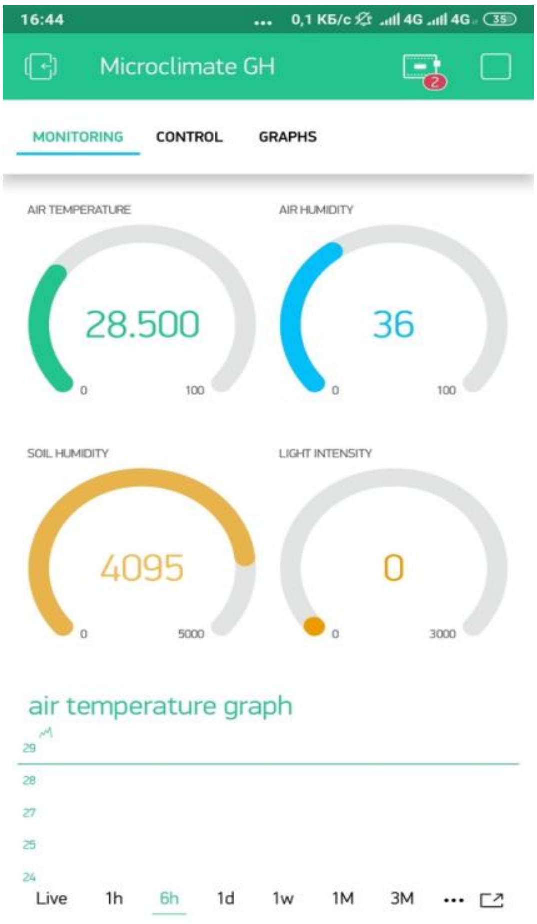
Fig 7.Greenhouse in working process.



(a)



(b)



(c)

Fig 8. A) Monitoring mode: show values and histograms; b) Control Unit; c) Monitoring mode: plots.

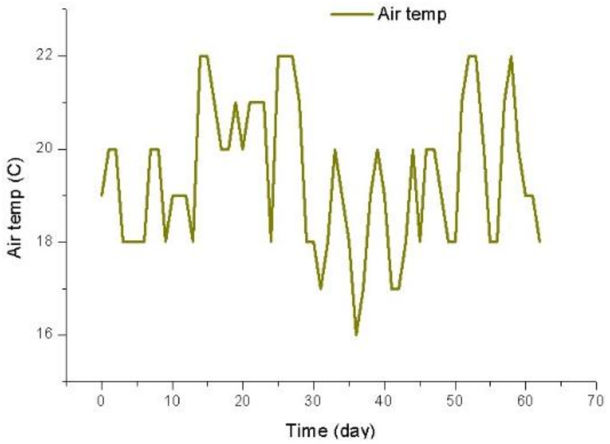


Fig9(a) Process monitoring air temperature

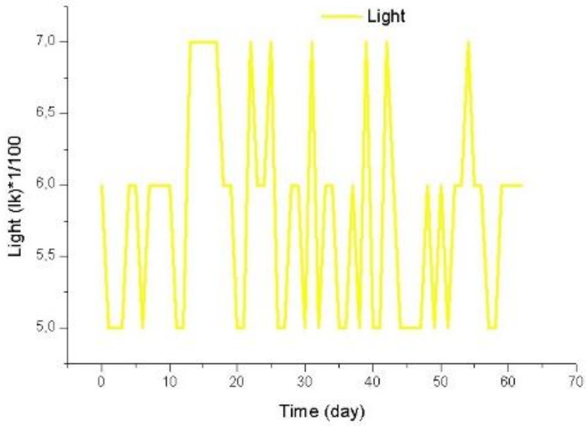


Fig9.d) Process monitoring light.

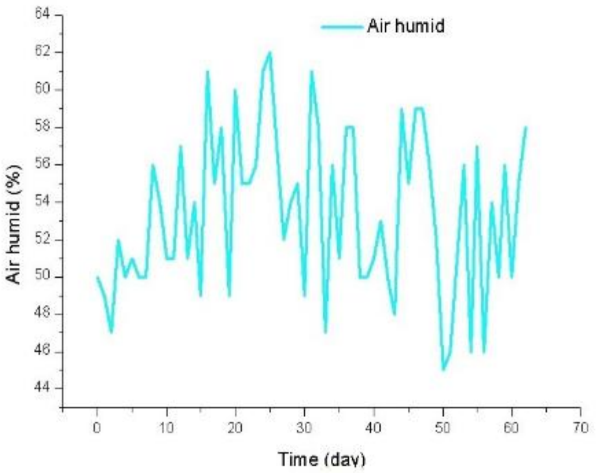


Fig9 b) Process monitoringair humidity

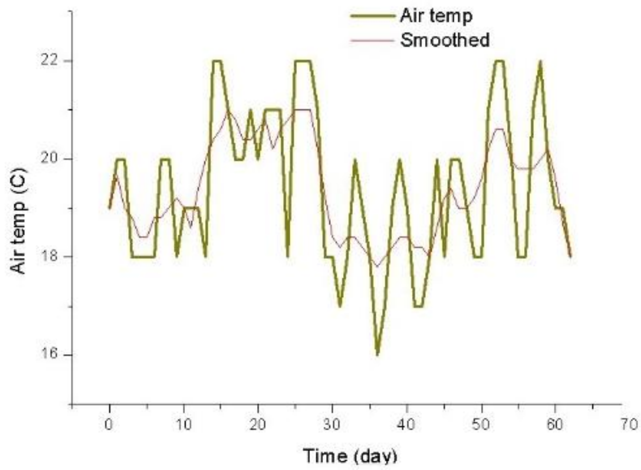


Fig10.Process monitoring with smoothing operation: a) Air temperature

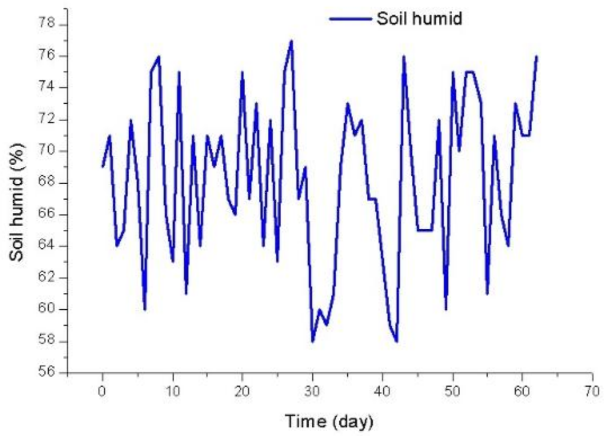


Fig9 c) Process monitoring soil humidity

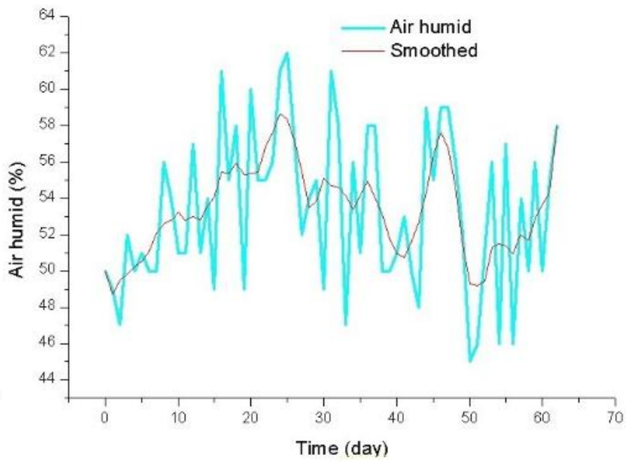


Fig10.Process monitoring with smoothing operation: b) Air humidity

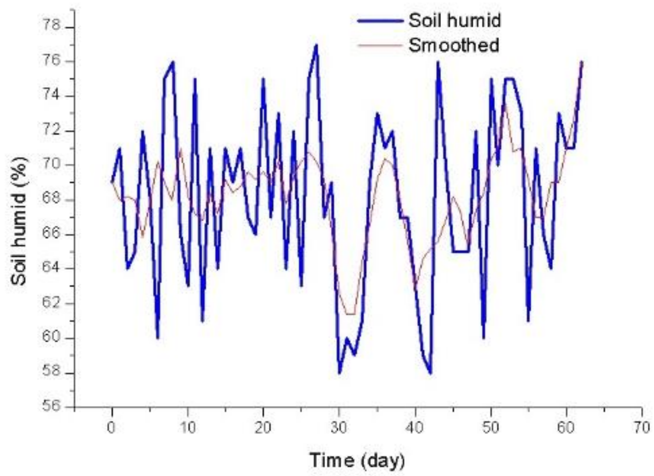


Fig10.Process monitoring with smoothing operation: c) Soil humidity

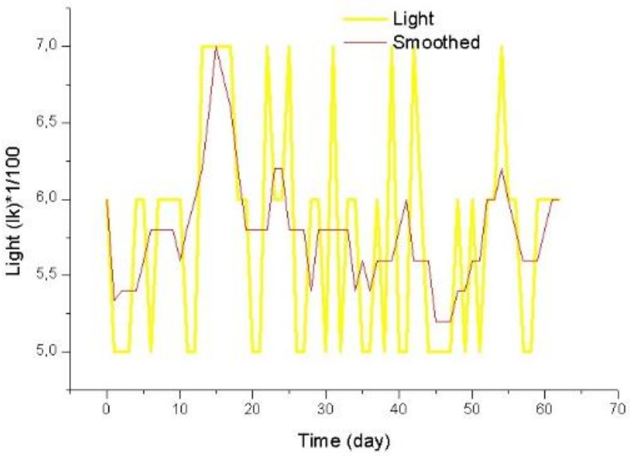


Fig10.Process monitoring with smoothing operation: d) Light.

Table 3. Standards for growing tomato in a greenhouse and sensor measurement results

Parameters	Norm (task)	The average value of the adjustable value
Air temperature, C	*x*1 ∈ [18; 22]	$\overline{y}1$= 19.39
Air humidity, %	*x*2 ∈ [50; 60]	$\overline{y}2$= 53.36
Soil moisture, %	*x*3 ∈ [60; 80]	$\overline{y}3$= 68.20
Lightning, lk	*x*4 ∈ [500; 600]	$\overline{y}4$= 577

IV. CONCLUSION

The "Microclimate GH" system was developed as part of study, it differs from its other prototypes in its accessibility to a wide user, good design and construction, and allows:

a) to carry out accurate measurements and monitoring of the microclimate of the home mini-greenhouse in real time through a mobile and web application;

b) monitoring data shall be saved as historical data and shown to the user in the reports and graphs form and will be available for analysis at any time;

c) based on the analysis of historical data, it is possible to assess the state of the control process and help the user to take the necessary measures in a timely manner;

d) to increase the productivity of the user-vegetable grower.

The system implements the IoT and WSN functions:

- the access to the application from anywhere in the world and location;
- user video instruction output;
- output of reports on the results in the form of graphs, histograms, audio signal;
- sending a message to the user as the monitoring process state;
- manual control of three processes: cooling, watering and lighting.

It is planned to add adaptive control functions to the system. It will be implemented through neural network technologies and, depending on changes in the microclimate conditions, the system will automatically adjust and generate optimal control.

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This system maintains the microclimate conditions for growing tomatoes and is available to the Kazakhstan user (the cost of the system is 34,700 tenge, that is, its price is not higher than the average salary of a Kazakhstan), the economic effect of using the system is 10,000 tenge, the payback period of the greenhouse is 4 seasons.

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