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Developing Software and Hardware for Micro-climate Unit

Diplomová práce

Studijní program: N2612 – Electrical Engineering and Informatics
Studijní obor: 3906T001 – Mechatronics

Autor práce: **Yegor Boyarchikov**
Vedoucí práce: Ing. Lukáš Hubka, Ph.D.

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Faculty of Mechatronics, Informatics
and Interdisciplinary Studies

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Master thesis

Study programme: N2612 – Electrical Engineering and Informatics
Study branch: 3906T001 – Mechatronics

Author: **Yegor Boyarchikov**
Supervisor: Ing. Lukáš Hubka, Ph.D.

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DIPLOMA THESIS ASSIGNMENT

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1. Create a model of an environment to describe (predict) the outside condition (temperature, humidity, etc.).
2. Design the general architecture of the micro-climate system for the hardware design.
3. Perform an overview of hardware elements.
4. Develop the software to control the system (micro-climate unit).
5. Perform system tests.

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[2] Petin, V. Projects based on Arduino platform. 2nd ed., BHV-St.Petersburg, 2015. ISBN 978-5-9775-3550-2.

[3] Gun'ko, A., V. Statistical methods of signals prognosis. Novosibirsk: NSTU publishing, 1996. ISBN 5-7782-0073-0.

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Abstract

The goal of this thesis is to develop a low level of the automated microclimate control system.

The lower level is a software and hardware complex that provides an opportunity to receive information from the sensors. The complex allows user to transfer data to the controller, as well as receive control signals for the executive elements of the system from the web server. One of the most important advantages of this complex is presence of two control modes: automated mode and automatic mode.

Automated mode allows user to set parameters and maintain them at the required level manually in on-line mode.

Automatic mode allows us to set values once, after setting of desired values the system will maintain conditions at the object within the selected limits using executive mechanisms.

Going back to the structure of the system, it is important to mention that sensors will be situated both inside the object and outside. This approach is used to improve quality of the control. Moreover it allows us, as designers, to use an expert system. Expert system will be situated at the high level of the system.

Keywords

Automated microclimate control system, controller, sensor, actuator, C programming language, Arduino IDE.

Table of content

Introduction

Qualitative control of microclimate parameters at the required level is an important component in the functioning of greenhouse enterprises. In connection with the active development of the agricultural complex, increasing of the amount of the products obtained in this sphere and the current economic situation, it is necessary to pay great attention to this problem. Right chosen technology for maintaining the microclimate is an important component that allows us to increase yields and improve quality of the products, as a result, the efficiency and competitiveness of production as a whole. Also one of the most important moments is rational use of energy resources. That is an additional opportunity to significantly reduce the cost of the production process. The modern automated climate control system should support not only established operating mode, but also make maximum use of the capabilities of the executive system and easily built in the greenhouses of any configuration and size.

Nowadays, most of the engineers prefer to increase the number of the executive systems during the modernization of the greenhouses: updating ventilation systems, installing curtain walls, installing fans, placing relays, lighting systems, irrigation systems of various configurations and designs. It is important to note that increasing amount of the executive systems at the greenhouses, leads to high price of maintaining it in a working state. However, in our case, the emphasis is on low price, extensibility and simplicity of operation. This feature of the developed system will ensure its popularity, both at the community of professional farmers, and ordinary gardeners, who will use this system at their gardens. Based on such principles as extensibility and simplicity of use in couple with low price of our system, users can build multiunit system with the number of low levels more than one, unite them into network. Summarizing previous information it could be said that our system implements the concept of the Internet of Things.

Also, during the research it was decided to pay big part of the attention to such important aspects as: methods and algorithms of the statistical signal prognosis, anti-interference methods and algorithms of the incoming signal processing.

Coming back to the hardware part, it is important to notice that in addition to the controller, the automated microclimate control system includes a set of sensors for measuring parameters inside the greenhouse. To transfer control signals to the actuators and executive mechanisms, system includes hardware-software tools which provide an opportunity to control parameters at the greenhouse not only in manual mode, but also in automatic mode.

One of the most important elements of the microclimate control system of greenhouse is the subsystem of self-diagnostics which provides an opportunity to detect failures in time. Frequent changes of air temperature, humidity, additionally with the wear of actuators and executive mechanisms can lead to partial failure of the system. One of the most important elements of the greenhouse microclimate control system is the self-diagnostic subsystem, which enables timely detection of failures.

Frequent changes of air temperature, humidity, additionally with the wear of actuators and executive mechanisms can lead to partial failure of the system.

The methods of detection and diagnostics which are built into the system allow us to identify non-standard situations, and maintain the parameters of the microclimate with the minimum possible deviation. If it is impossible to fix the situation without human intervention, the system sends an appropriate alarm message.

According to the existing experience in the implementation of the automated control systems, it can be concluded that during the design stage of the system it is difficult to choose a single management method. Modern control system should be easy understandable for users of a different level, moreover such system has to provide the possibility of simple configuration of the parameters at the greenhouse complexes, provide the opportunity to impact and making changes to the operation of the system remotely.

Actuality

Nowadays, extension of the Internet gave us an opportunity to use web-resources any time everywhere using any appropriate device. This fact could not be ignored, in order to the previous statement it was realized that the most optimal and suitable way to implement control interface of the system is the using of web-server, which will provide us with following user's options: displaying and storing information about the state of the microclimate, direct control of the executive systems. A web server is a server that accepts HTTP requests from clients, usually web browsers, and gives them HTTP responses, usually along with an HTML page, image and file.

The aim of the research

The aim of the thesis is to develop hardware and software for microclimate control unit. The microclimate unit is a software and hardware complex that allows us to receive data and bring it to the controller, and also receive control signals from the user through the web server and then transfer them to the executive elements of the system.

To achieve the goal of the final work, it is supposed to solve the following tasks:

1. Development of the system architecture.
2. Overview and selection of hardware components of the system.

3. Development of the program parts of the system.

4. Testing.

Methods of the research

The analysis of different methods and algorithms of the incoming signal processing was used as the main approach to the research procedure in this work. Results and data received during the experiments were tested on the developing microclimate control system.

Main aspects of the scientific research

Diploma thesis includes following key aspects:

1. Algorithm for processing input signals from external sensors of the microclimate control system.
2. Functionality that allows user to receive, as well as process data not only from internal sensors of the microclimate control system, but also from external sensors of the system.
3. Software and hardware solutions for the microclimate control system, which allow us to perform intelligent data analysis and predict possible changes at the top level of the system.

General structure of the dissertation

This work consists of an introduction, includes three main chapters and a conclusion.

The introduction shows the relevance and practical value of the work, set aims and objectives of the research.

The first chapter describes the architecture and includes a review of the hardware components of the automated microclimate control system.

The second chapter of the thesis consists of the program part of the low level of the system and the structure of the software with descriptions of algorithms applied in this project.

The third chapter of the dissertation is devoted to the results of testing the microclimate control system; the results of the development are also shown.

The tasks that were solved during the research process are described in conclusion.

Also conclusion includes brief overview of the main ideas and solutions applied in the work.

1 System's architecture, review of the hardware

1.1 Main definitions

Automated control system (abbreviation ACS) is a hardware and software complex, designed to manage various processes within the technological process, enterprise, production. ACSs are used in various branches of agriculture, industry, energy, transport and in many others spheres. The term "automated", in contrast to the term "automatic", emphasizes the retention of the most general non-automatable functions for the user-operator. Automated control systems with the Decision Support System (DSS) are the main tool for increasing the validity of management decisions.

This work is devoted to the automated microclimate control system, or rather its lower level. The lower level of the developing system contains the following components: microcontroller, Ethernet data transmission module, GSM module intended to provide an alternative method of the connection with lower level of the microclimate control system, a set of temperature and soil moisture and air temperature sensors, located both inside and outside of the greenhouse, a set of actuators, including electromechanical relays, servo motors and water supply pumps.

The microcontroller is a special microcircuit intended for control of electronic devices and also it provides such important option as interaction between them in accordance with the program put into it. Microcontrollers (Figure 1.1), in contrast to microprocessors that are used in personal computers, contain built-in additional devices. These devices are called peripheral. The use of a powerful computing device with a wide range of capabilities built on a single chip instead of a whole set in a modern microcontroller allows to significantly reduce the size, reduce power consumption and cost of devices built on its base. Nowadays, microcontrollers are used in various industries: automatic control systems, as in our case, in computer technology, electronics. The main characteristics of microcontrollers include: clock frequency, operating supply voltage, amount of digital and analog inputs and outputs.

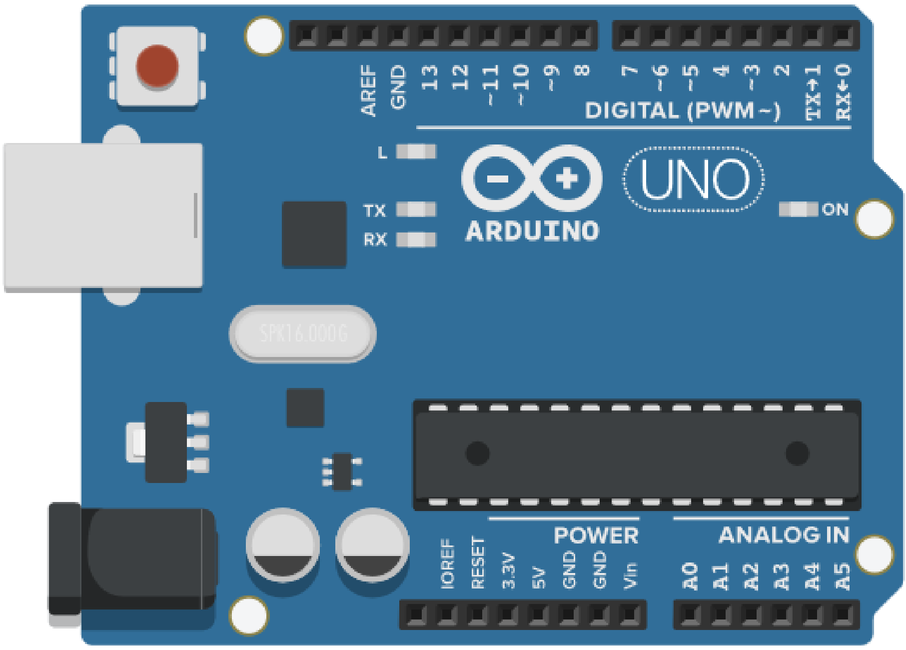

Figure 1.1- Arduino microcontroller.

An Ethernet module (Figure 1.2) is used for data transfer to the upper level, this module is used to connect the microcontroller to the Ethernet network via a TCP / IP cable and provide further communication between lower and upper level of the automated microclimate control system via the Internet. The main characteristics of such modules are data transmission speed, working voltage, supported protocols.

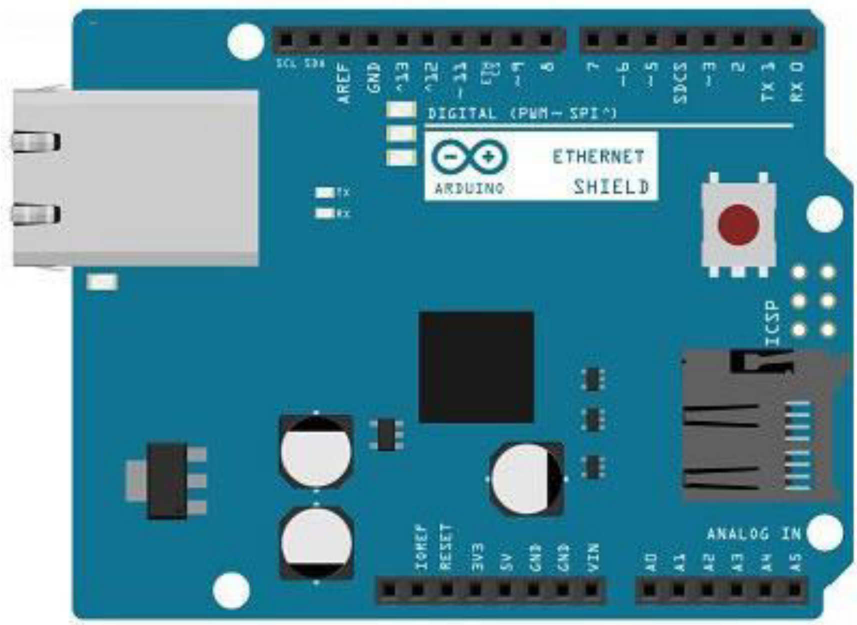

Figure 1.2 - Ethernet module.

GSM module is a device that allows us to organize the interaction of the user with the system on the radio channels of cellular communication. The main characteristics of GSM modules (Figure 1.3) are the range of operating frequencies and the level of power consumption.

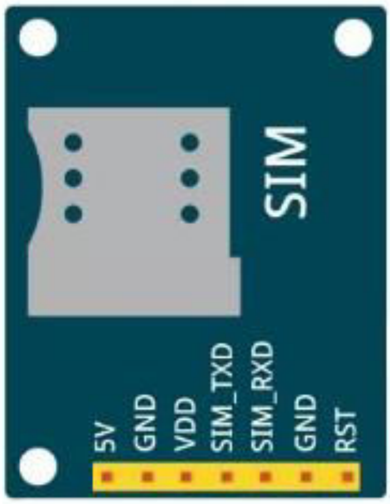

Figure 1.3 - GSM module.

The sensor is a measuring device designed to generate a measurement information signal in a convenient form for transmission, further conversion, processing and storage, but in not user-perceptible form. The sensors (Figure 1.4), based on electronic equipment, are called electronic sensors. A separate sensor can be designed to measure and control one physical quantity or several physical quantities at the same time.

The main characteristics of electronic sensors are sensitivity and error.

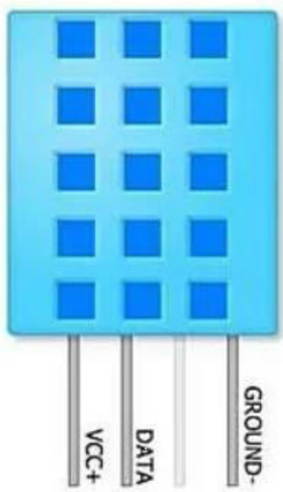

Figure 1.4 – Air temperature and humidity sensor.

The executive mechanism is a device in the automatic control system that directly performs the mechanical movement, the rotation of the regulating body of the control object. By type of drive it is used to divide for following categories: hydraulic, pneumatic, electric and combined actuator, electrohydraulic or electromechanical. The main characteristics of actuators (Figure 1.5) include such parameters as, operating voltage, power consumption, the force created at a certain electrical voltage.

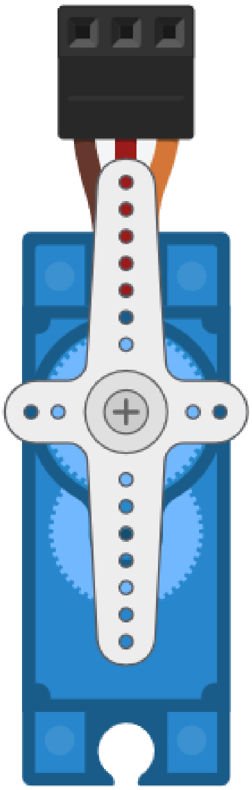

Figure 1.5 - Executive mechanism, implemented as servo motor.

1.2 Choosing of system's structure.

One of the most important points during the process of the automated control systems design is choosing of the system's structure. Let's take look at the most common structures. It was decided to divide industrial ACS to the following categories: centralized, decentralized, centralized dispersed, hierarchical.

1. Centralized structure

Centralized structure allows performing all control processes in a single control unit. This control unit is responsible for data collecting, data processing, based on the data, control unit perform their analysis in accordance with the laid down criteria of the system and generates control signals. Appearance of such structure is closely connected with growing amount of the parameters and territorial dispersal of the control object.

Advantages: simplicity of the data transmission between the parts of the system, maximum operational efficiency with minimal redundancy of technical controls elements.

Disadvantages: proper level of the control requires high level of the reliability and productivity of the system's elements, evidently high total length of communication channels in the presence of territorial dispersal of control objects.

2. Decentralized structure

This type of the automated control systems could be applied when designers want build ACS with independent objects of control over material, information, energy and other types of resources. This class of the systems is combination of subsystems which are not depend from each other, moreover each subsystem contains own informational and algorithmic base, this option allows to perform independent operating. System requires information about the state of a particular object in order to perform control action on this control object.

Advantages: flexibility of the system, high level of reliability provided with system's redundancy.

Disadvantages: low mobilization abilities, in the general case, a large reaction time of the system to external influences.

3. Centralized dispersed structure

Principle of the centralized control is the highest goal of this structure. This means that the system produce control signals for each control object according to the information of the state of all control objects in general. Some of functional is common for all of the system's channels. System use switches to connect to the individual functional elements of the channel; this allows implementing closed loop control.

The main control algorithm in this case consists of a set of interrelated object management algorithms that are implemented by a set of mutually related controls.

During the operating process each control element performs data reception and processing of relevant information, as well as the issuance of control signals to subordinate objects. In order to implement the control functions, each local authority, as necessary, enters into the process of information interaction with other control bodies.

Advantages: reducing of the quality and productivity requirements for each processing center without any loses at the control process, reducing of the high length of the common communication channels.

Disadvantages: the complexity of information processes in the control system due to the need for data exchange between the processing and control centers, as well as the correction of stored information; redundancy of technical means intended for information processing; the complexity of synchronization of information exchange processes.

4. Hierarchical structure

With the increase of number of control tasks in complex systems, the amount of processed information increases significantly and the complexity of control algorithms increases too. As a result, impossible to control centrally, since there is a discrepancy between the complexity of the control object and the ability of any control elements to receive and process information.

In addition, in these systems, developers can distinguish the following groups of tasks, each of which is characterized by corresponding requirements for the time of reaction to events occurring in a controlled process:

- Information tasks for administrative management, tasks of dispatching and coordination in the scale of the workshop, enterprises, planning tasks and other tasks of this kind, the reaction time can be hours in this case;
- Extreme control tasks associated with the calculation of the desired parameters of the controlled process and the required values of the controller settings, with the logical tasks of starting and stopping aggregates and other equipment. The reaction time for solving such problems can reach seconds, minutes;

- Data collection tasks and direct digital control tasks, the reaction time for these tasks, seconds, or even a fraction of seconds;
- Optimization tasks and adaptive processes control tasks, technical and economic tasks, response time, when it comes to tasks of this type can be several seconds.

Obviously, the hierarchy of management tasks leads to the need for creation of a hierarchical system of management tools. Such a division, allows to cooperate with information difficulties for each local control element, generates the need to harmonize the decisions made by these elements, it means the creation of a new control element over them. At each level, the maximum compliance of technical equipment characteristics with a given task class should be ensured.

Advantages: clear system of interrelationships such as "boss-subordinate", explicit responsibility, the presence of a rapid response to direct control impacts, relative simplicity of building the organizational structure of management, high degree of "transparency" of the activities of all structural units.

Disadvantages: excessive load on the basic level of control, lack of support elements, lack of the ability to quickly resolve issues arising between different structural elements, critical dependence of low levels to the higher level.

It was decided to use centralized dispersed structure of the automated control system in this project. The choice was made according to the following aspects:

- Extensibility of the developed system;
- Scalability of the developed system, involves the placement of system elements on several automation objects simultaneously;
- Increasing the reliability of the system as a whole, due to the distribution of system functions between the upper and lower levels of the system;

1.3 Hardware elements of the systems

The low level of the automated microclimate control system is a hardware and software complex based on the Atmel ATmega 328 controller, using single-channel and multichannel electromechanical relays SRD-05VDC-SL-C, humidity and air humidity sensors DHT-11, soil moisture sensors FC-28, located inside of the greenhouse complex, air temperature sensors DS18B20, placed outside of the greenhouse complex, GSM module SIM800L, Ethernet module W5100, servo drives Tower Pro MG996R, ventilation units, supplied with power by the alternating current network with a voltage of 230V ±10% and an electric current frequency of 50Hz ±0,2Hz, as well as water pumps operating from an alternating current network with a voltage of 230V ±10% and an electric current frequency of 50Hz ±0,2Hz.

1.4 Structural diagram of the system

According to the task in hand, the system should be a hardware-software complex made of the hardware elements described above, which allows the user to obtain temperature data, humidity of air and soil, both from sensors located inside the greenhouse complex and outside, in the real-time mode. The system should receive control signals from the user from the web server with their subsequent transfer to the actuators of the system, represented by servo motors and electromechanical relays. The system generates control actions, and with the help of lights connected to the relay, a water pump, a ventilation system, switches the lighting on and off, turns on or off the irrigation, switches the ventilation on or off, and opens or closes the ventilation pans with the help of the servo motors, climate control has the function of informing the user through SMS.The SMS notification function is implemented by sending SMS messages with a code word to the SMS system, in response to which the system sends an SMS report with current data on humidity and temperature of soil and air in the greenhouse. According to the features, described above, the structural diagram of the system has the following form (Figure 1.6)

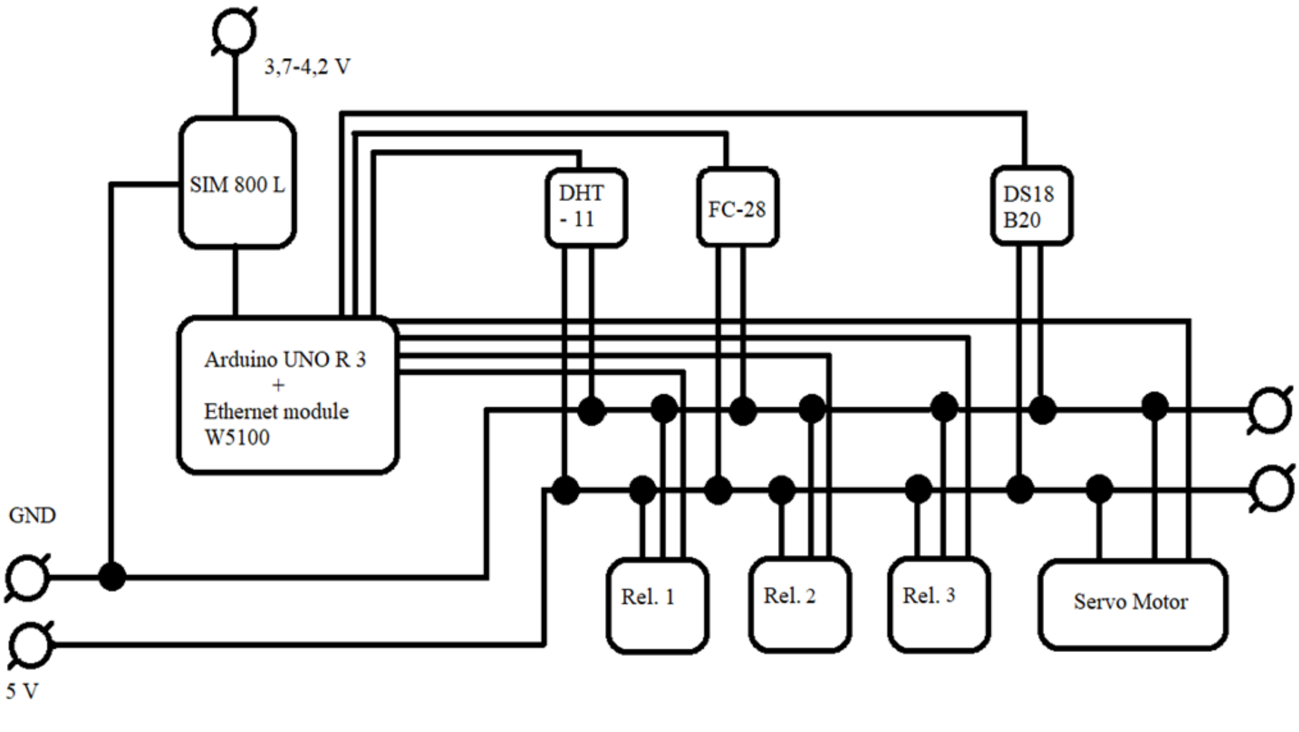

Figure 1.6 - Structural diagram of the developed system.

DHT-11 temperature and humidity sensors could be connected to the digital inputs / outputs (D0-D13) of the Arduino UNO platform. The humidity sensors FC 28 could be connected to analog inputs (A0-A5). External DS18B20 air temperature sensors could be connected to digital inputs / outputs (D0-D13). Electromechanical relays (Rel.1 - Rel.3) could be connected to digital inputs / outputs (D0-D13). The Servo Motor could be connected to digital inputs / outputs (D0-D13).

1.5 Advantages of the Arduino microcontrollers

Nowadays most of people do not pay attention to the principles of PC's functioning. Users often run necessary software products, applications and work with them. Similarly to the above-described principle, the Arduino family of controllers allows the user to focus on project development, rather than on studying the device and the principles of the operation of individual elements. Working with a family of data controllers, the developer is not so keen on the need to work out and create new boards and modules. In most cases, it can use the ready expansion cards or directly connect the necessary elements to the controllers of the Arduino family. All other efforts can be directed to the development and debugging of the control program in a high-level language. As a result, the combination of these features opens up wide access to the development of microprocessor devices, not only for highly skilled professionals, but also for people who have more modest knowledge of such complicated for the unsophisticated developer areas as electrotechnics and electronics. The availability of ready-made, as hardware modules, executed in the form of ready-made, easily plug-in boards, and program modules executed in the form of ready libraries, allows developers to create ready-made devices in a short time to solve the tasks. The options for using Arduino family controllers are limited only by their own capabilities, embedded in them in production, and, of course, by the desires and fantasies of the developer.

1.6 Reliability of the microcontroller

Reliability is one of the most important characteristics of the automated microclimate control system. According to this idea, it was decided to choose the controller, which contains modern mechanisms of protection from failures such as, for example, Watchdog timer. When such important things are under discussion, designers have to pay attention to the fact that most embedded systems need to be self-reliant. It is not usually possible to wait for someone to reboot them if the software hangs. Some embedded designs, such as remote greenhouses, are simply not accessible to human operators. If their software ever hangs, such systems are permanently disabled. In other cases, the speed with which a human operator might reset the system would be too slow to meet the uptime requirements of the product.

A watchdog timer is a piece of hardware that can be used to automatically detect software anomalies and reset the processor if any occur. Generally speaking, a watchdog timer is based on a counter that counts down from some initial value to zero. The embedded software selects the counter's initial value and periodically restarts it. If the counter ever reaches zero before the software restarts it, the software is presumed to be malfunctioning and the processor's reset signal is asserted. The processor (and the embedded software it's running) will be restarted as if a human operator had cycled the power [1].

Automated systems which do not require manual control are also suffer from errors, hangs and other failures (including hardware failures), including such components as watchdog timers to the automated microclimate control systems increases stability - there is no need for manual reset.

1.7 Hardware components overview

Arduino UNO R3 controller

The Arduino Uno R3 controller (Figure 1.7) is based on the ATmega328 microcontroller. There are 14 digital inputs / outputs (6 of which can be used as PWM outputs), 6 analog inputs, a 16MHz crystal oscillator, a USB connector, a power connector, an ICSP connector and a reset button on the platform. The microcontroller has three types of memory: 32KB flash (FLASH), 2KB RAM (SRAM), 1KB of non-volatile memory (EEPROM). To start working, user has to connect the platform to the computer using a USB cable, or by powering using an AC / DC adapter or battery. The adapter is connected through a connector with a diameter of 2.1 mm (central contact - positive).The battery is connected to the GND and Vin terminals of the POWER connector. The voltage of the external power supply can be in the range of 6V - 20V. It is recommended not to allow the voltage drop below 7V otherwise it can cause unstable operation of the device. It is also undesirable to increase the supply voltage by more than 12V, as this can lead to overheating of the voltage regulator and to disable the microcontroller. Summarizing, it could be concluded that the recommended voltage range is 7V - 12V. Unlike other controllers (Arduino Pro Mini, Arduino Duemilanove, Arduino Nano, Arduino LilyPad) using FTDI USB microcontroller for USB communication, Arduino Uno R3 uses microcontroller ATmega16U2 . The controller is programmed from the integrated software environment Arduino (IDE). Programming takes place under the management of a resident bootloader using the STK500 protocol. A hardware programmer is not required. It is also worth noting that the Arduino UNO R3 controller has a universal form factor that allows you to connect additional modules to it, such as expansion cards, Wi-Fi modules or Ethernet modules [2].

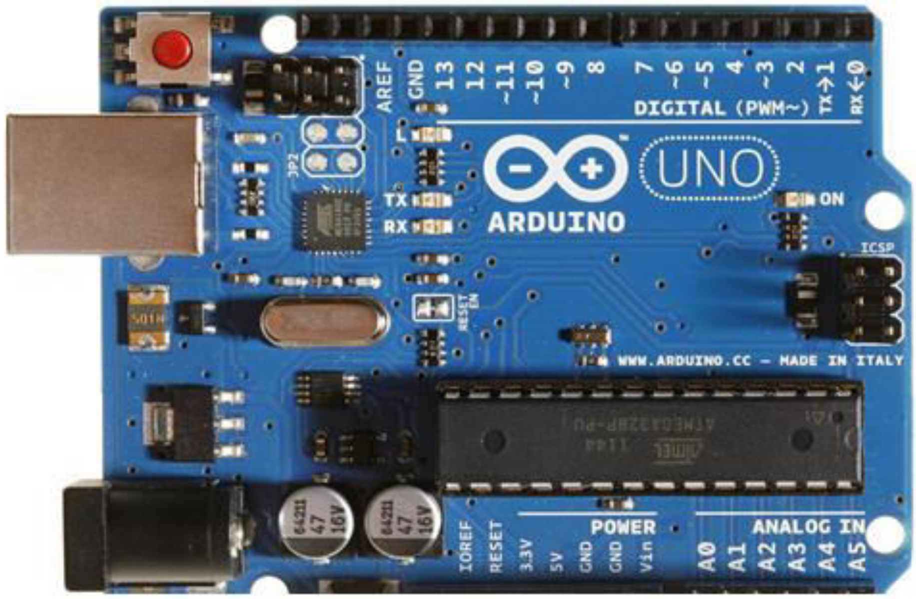

Figure 1.7 - Arduino UNO R3 microcontroller.

Arduino Uno R3 microcontroller's characteristics are shown in Table 1.1.

Table1.1. Characteristics of the Arduino Uno R 3

Microcontroller	ATmega328
Operating voltage	5V
Input voltage (recommended)	7V-12V
Input voltage(critical)	6V-20V
Digital inputs/outputs	14(could be used as PWM)
Analog inputs	6
DC through input/output	40mA
DC for input 3,3V	50mA
Flash	32Kbytes, 0,5Kbytes are used for boot loader
RAM	2Kbytes
EEPROM	1Kbyte
Clock frequency	16 MHz
Microcontroller	ATmega328

Ethernet module W5100

Ethernet module W5100 (Figure 1.8) is used to connect the Arduino UNO R 3 microcontroller to the Ethernet network. It is connected to the network by the usual TCP / IP cable installed in the RJ45 connector of the module. The Ethernet module W5100 can be used as a small web server. There is a micro SD card installation container mounted, this feature allows storing data on the board. The main component of the W5100 Ethernet module is Wiznet's W5100 chip. This chip hardware implements the following transport, network and link layer protocols: TCP, UDP, IPv4, ICMP, ARP, IGMP and MAC. An important feature is the hardware support for PPPoE protocol (Point-to-point over Ethernet) with PAP / CHAP authentication protocols, this feature allows remote connection of the embedded device to the provider via a DSL modem operating in bridge mode and not having its own hardware support PPPoE.

A transformer is integrated into the cable outlet, which provides galvanic isolation of the module from the information network. There is a reset button. When working together with Arduino, the power comes from the main module. The information from the network and from the micro SD is sent to the controller via the SPI bus lines.

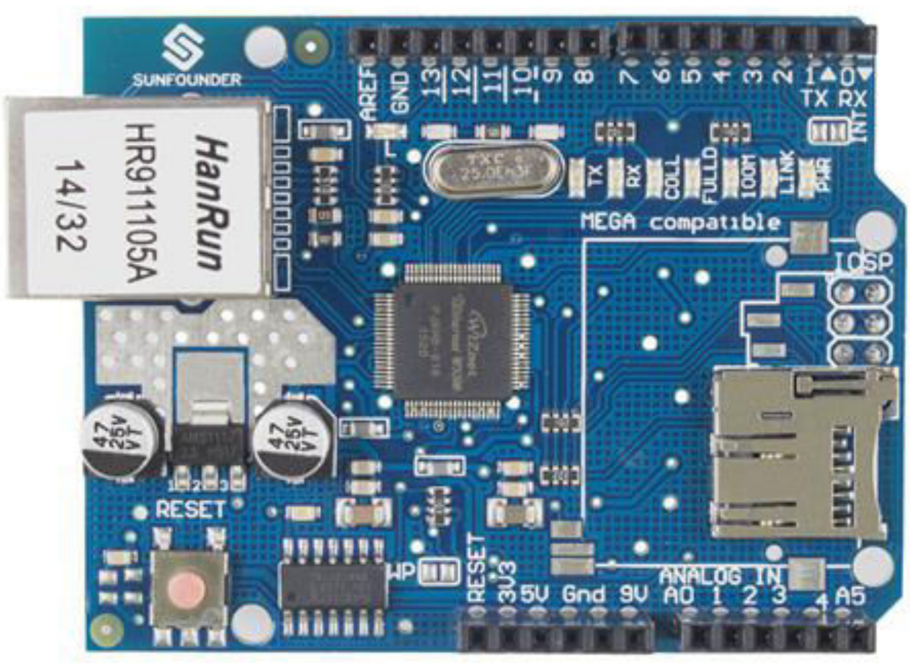

Figure 1.8 - Ethernet module W5100.

Ethernet module W5100 characteristics are shown in Table 1.2.

Table1.2. Characteristics of the Ethernet module W5100

Operating voltage	5V
Internal buffer volume	16Kbytes
Speed of connection	10Mbit/s and 100Mbit/s
Maximal amount of connections	4
Operating interface	SPI

GSM module SIM800L

The compact GSM module SIM800L (Figure 1.9) is designed to work with SMS, calls, GPRS data transfer. Most AT commands are compatible with the GSM module SIM800L. The module starts automatic search for the network when power is applied. The built-in LED flashes slowly when there is a signal, flashes quickly when there is no signal.

The module can be controlled either from a computer (via a USB-UART TTL converter) or through the microcontrollers of the STM, Arduino, Raspberry Pi families.

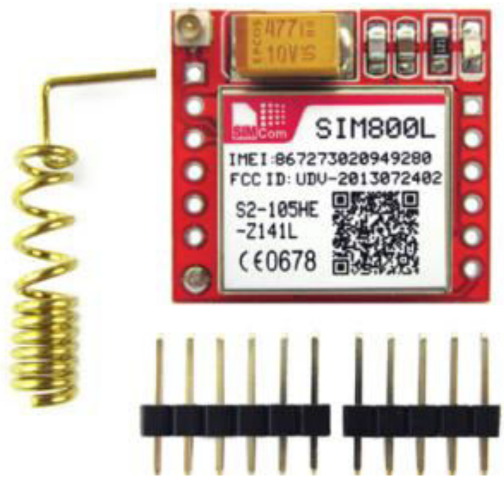

Figure 1.9 - GSM module SIM 800L.

GSM module SIM 800L characteristics are shown in Table 1.3.

Table1.3. Characteristics of the GSM module SIM 800L

Operating voltage	3,7V - 4,4V
Supported carrier ranges	GSM 850/900/1800/1900MHz
Power class	4 (2W in ranges 850/900MHz)
	1 (1W in ranges 1800/1900MHz)

Humidity and temperature sensor DHT-11

The DHT-11 sensor (Figure 1.10) is designed to measure the temperature and relative humidity of the ambient air directly in the greenhouse complex. This device is a stable and energy-efficient digital sensor that allows measurements with a relatively small error. The DHT-11 sensor consists of two main parts: a capacitive humidity sensor and a thermistor. Also there is ADC in casing for converting the analog signal to digital.

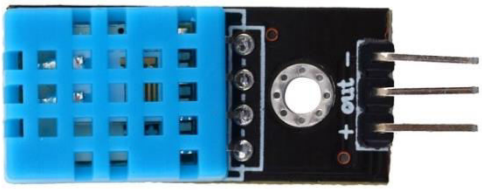

Figure 1.10 - Humidity and temperature sensor DHT-11.

DHT-11 sensor‘s characteristics are shown in Table 1.4.

Table1.4. Characteristics of the DHT-11 sensor

Operating voltage	5V
Air temperature measuring range	0°C –50°C
Air temperature measuring error	±2°C
Air humidity measuring range	20%-90%
Air humidity measuring error	±5%

Moisture and temperature sensor FC-28

Module FC-28 (Figure 1.11) is an analog sensor, it allows you to determine the moisture content of the soil. The tripping threshold is adjusted by a trimmer resistor.

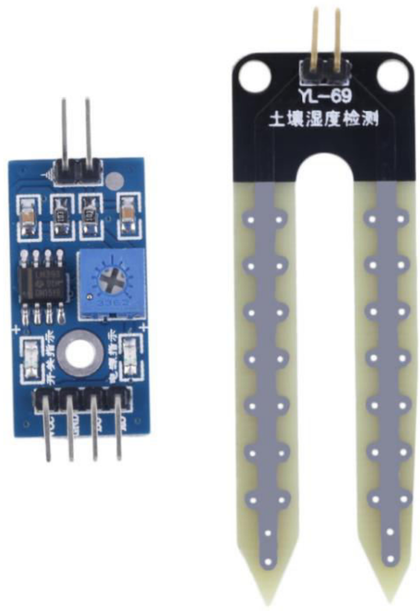

Figure 1.11 - Moisture and temperature sensor FC-28.

FC-28 sensor‘s characteristics are shown in Table 1.5.

Table1.5. Characteristics of the FC-28 sensor

Operating voltage	5V
Ground humidity measuring range	5%-90%
Ground humidity measurement error	±5%

Air temperature sensor DS18B20

DS18B20 (Figure 1.12) is a digital temperature sensor with many useful functions. In fact, the DS18B20 is a whole microcontroller that can store the measurement value, signal the temperature output beyond the established limits (the user can set and change the boundaries himself), change the measurement accuracy, the way of interaction with the controller, and much more. All this in a very small package, which, moreover, is available in waterproof design. The DS18B20 has three outputs, one is used for data, the other two are ground and power. The number of wires can be reduced to two, if you use a scheme with parasitic power and connect Vdd to ground. To a single data wire, several DS18B20 sensors can be connected at once, this feature of this sensor was the main reason for its use in the project, since the number of inputs necessary for the operation of several sensors at once remains equal to one and, thus, it is possible to save necessary inputs / outputs for connection other peripheral devices. Another not unimportant feature of this sensor is its own memory. The sensor memory consists of two types: operational and non-volatile - SRAM and EEPROM. Configuration registers and registers TH, TL, which can be used as general-purpose registers if not used to indicate the temperature range.

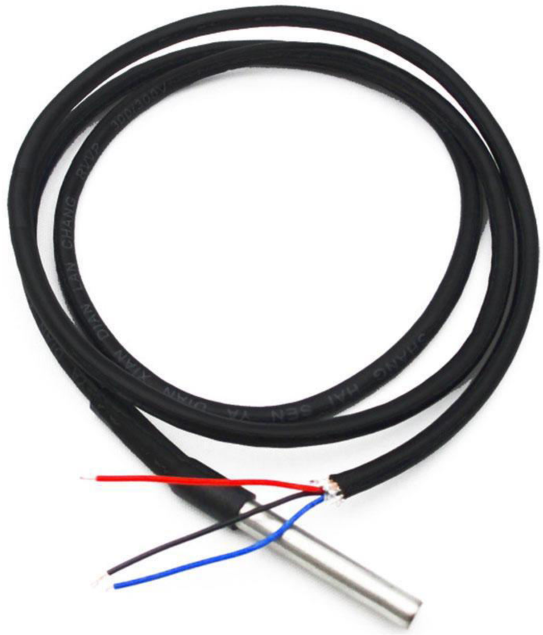

Figure 1.12 - Air temperature sensor DS18B20.

DS18B20 sensor‘s characteristics are shown in Table 1.6.

Table1.6. Characteristics of the DS18B20

Operating voltage	3,3V - 5V
Air temperature measuring range	-55°C – 70°C
Air temperature measuring error	±1,5°C
Maximal amount of the sensors connected	127
Air humidity measuring error	0,0625°C

Electromechanical Relays SRD-05VDC-SL-C

SRD-05VDC-SL-C - is a model of electromechanical relay from the company Songle (Figure 1.13). This model of the electromechanical relay is made in a sealed enclosure that allows controlling executive mechanisms, which need power from an alternating current network with a voltage of 230V ±10% and a frequency of 50Hz ±0,2Hz. For quick connection of the relay module, there are two groups of contacts (2.54 mm pitch), using them you can easily connect relay to the controller and the load.

Figure 1.13 - Electromechanical Relays SRD-05VDC-SL-C.

SRD-05VDC-SL-C characteristics are shown in Table 1.7.

Table1.7. Characteristics of the SRD-05VDC-SL-C

Rated operating voltage of the coil	5V
Rated operating current of the coil	71mA
Resistance of the coil	70Om
Power consumption	0,36W
Maximal switching current	10A
Maximal switching voltage(AC)	28V
Maximal switching voltage(DC)	250V
Working temperature	-25°C - +70°C

Servo Drive Tower Pro MG996R

The Tower Pro MG996R servo drive (Figure 1.14) is an improved version of the MG995 servo. This servo is very often used for installation on radio-controlled models of airplanes and gliders, and also as actuators at facilities with the use of automation. Compared with the previous model has an increased torque at a standard voltage of 4.8V - 7.2V.

Figure 1.14 - Servo Drive Tower Pro MG996R.

Servo Drive Tower Pro MG996R characteristics are shown in Table 1.8.

Table1.8. Characteristics of the Servo Drive Tower Pro MG996R

Rated operating voltage of the coil	4.8V - 7.2V
Response speed 4,8V	0.17 s/60°
Response speed 6V	0.14 s/60°
Effort 4,8V	9,4 kg
Effort 6V	11 kg
Angle of rotation	60°
Working temperature	0°C - +55°C

2 Software design

2.1 Software design. General structure of the program

In order to ensure interaction between the devices entering the system, it is necessary to develop following software modules:

1. Module that provides connection between controller and server
2. Executive mechanisms control module
3. Module for data transmitting from sensors to the server
4. GSM module which performs connection and checking incoming SMS
5. Module for sending SMS messages to the user

The scheme of the software modules interaction is given below (Figure 2.1).

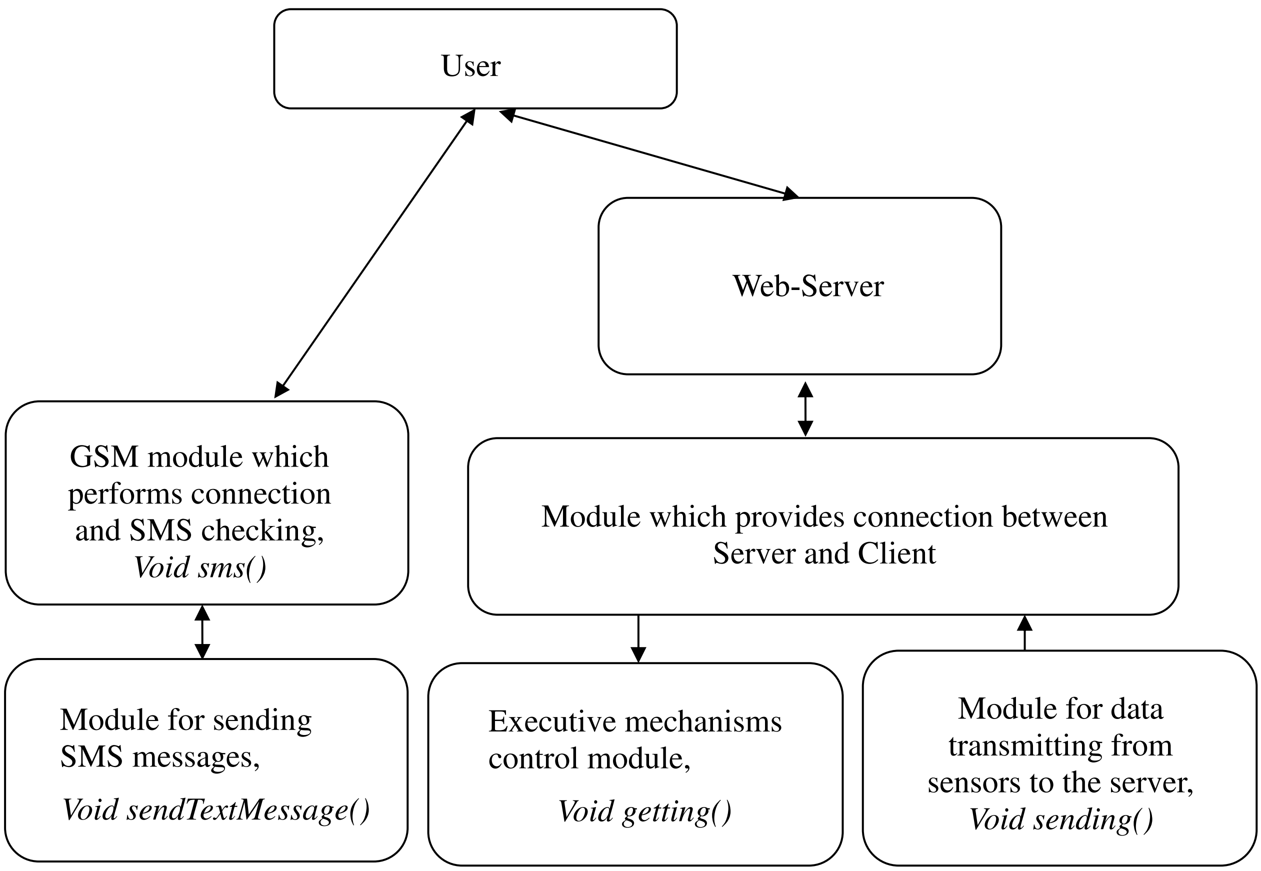

Figure 2.1 - Structure of the Software.

The program consists of the following modules:

1. The module providing the establishment of connection between the high and the low levels of the "Microclimate control system".

2. The control module of executive mechanisms allowing to receive, process and transmit commands coming from the website, and ensures correct operation of the actuators. The detailed mechanism of the module operation is displayed on the block diagram (Figure 2.2).

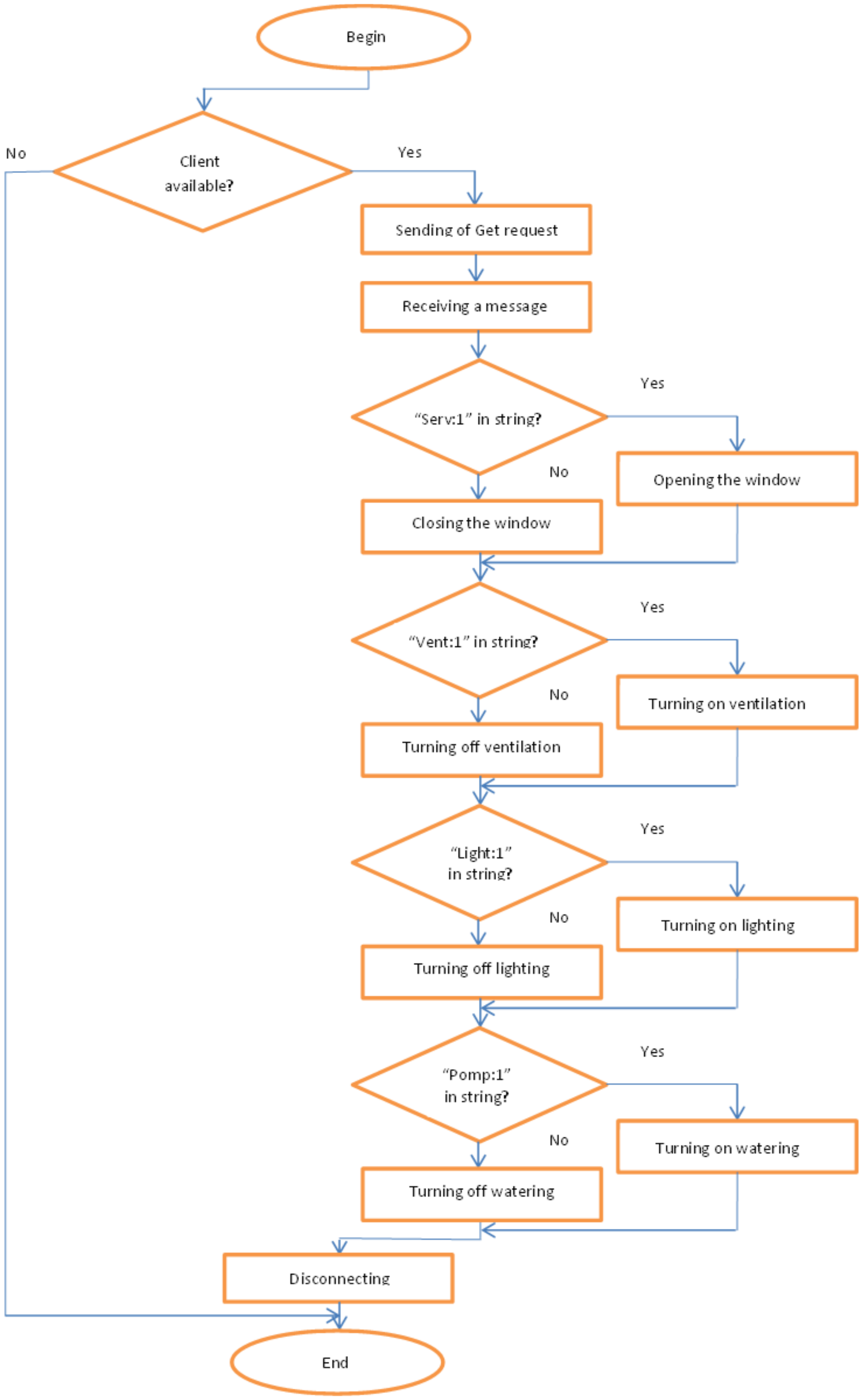

Figure 2.2 - Scheme for executive mechanisms control module.

3. A module for transmitting data from sensors to a website. This module allows the transmission of data on the state of the microclimate in accordance with the time intervals specified by the operator. The detailed mechanism the module's operating is displayed on the block diagram (Figure 2.3).

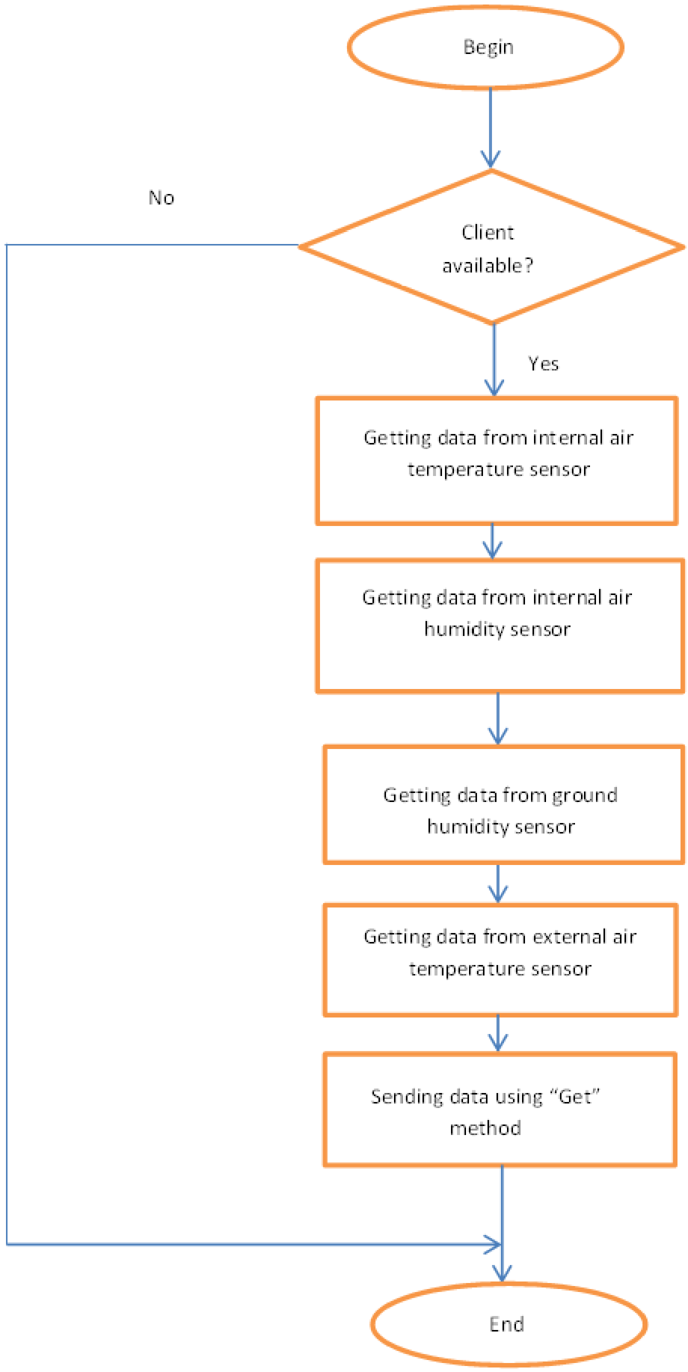

Figure 2.3 - Scheme for data transmitting module.

4. The module that provides GSM connections and performs checking of incoming SMS-messages allows you to connect the GSM-module and use it as an additional subsystem to inform the user about the microclimate, as well as to check incoming messages for the presence of a code word.

This approach is used to prevent unauthorized access and helps to avoid over-spending of funds on the SIM card used in the GSM-module.

5. The module for sending SMS-messages allows you to generate a report on the status of the climate parameters in the form of an SMS message and send them to the user. The detailed mechanism of the module operation is displayed on the block diagram (Figure 2.4).

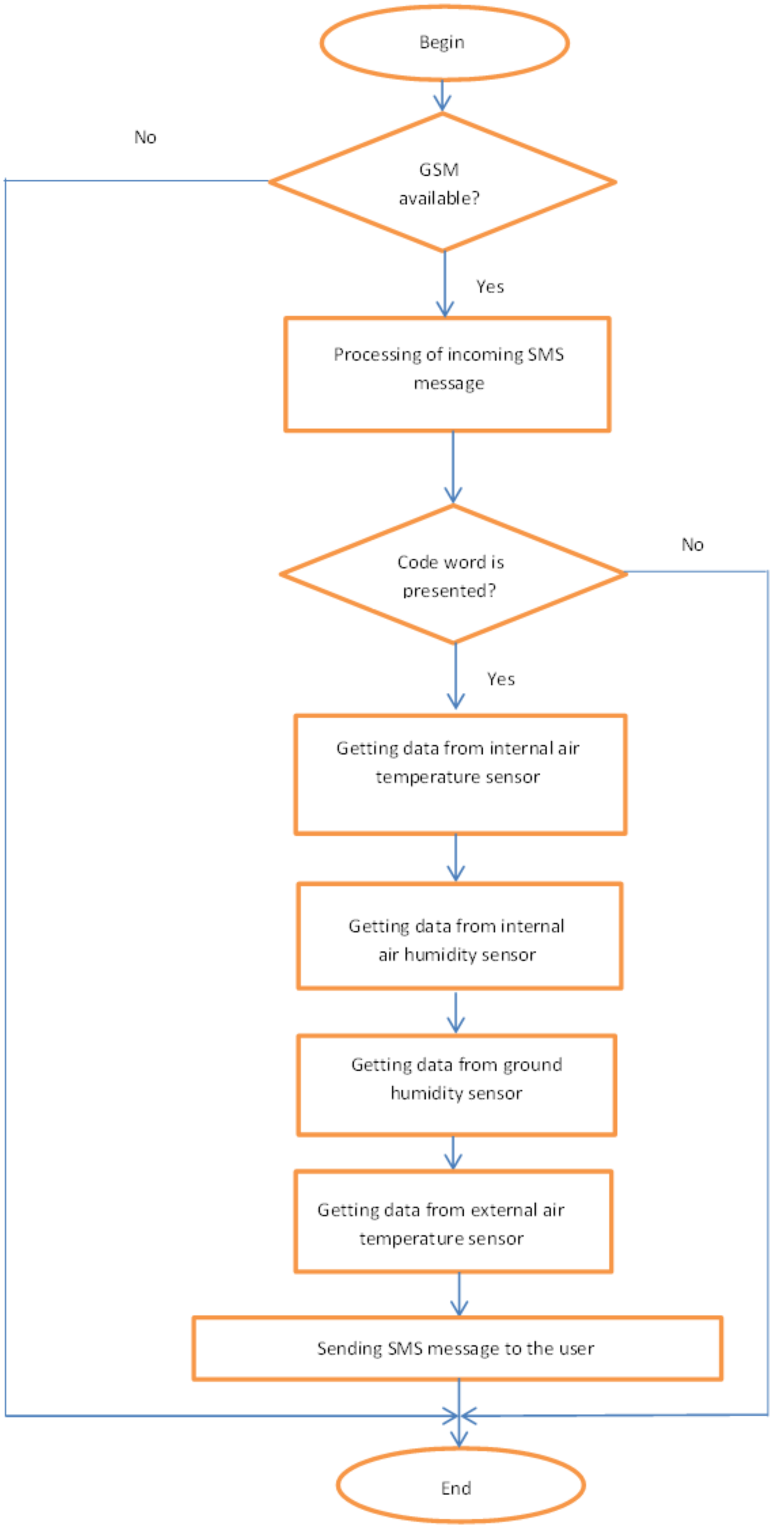

Figure 2.4 - Scheme for SMS-message sending module.

2.2 Pseudo-parallelism

During the process of development it was decided to use multi-threaded approach to interact with different data. In order to implement that decision it was decided to use special library "Thread.h". It is also important to understand the fact that Arduino does not support "REAL" parallel tasks (Threads), but it is possible to use this library to improve the code, and easily schedule tasks with fixed (or variable) time between runs. This Library helps to maintain organized and to facilitate the use of multiple tasks. Developer can use timers interrupts, and make it really powerful, running "pseudo-background" tasks under the rug. In our case software works using pseudo-parallelism, when the program is started, three threads are initialized: the stream of data transfer to the website, the flow of receiving commands from the website, the flow to work with SMS notification (Figure 2.5).

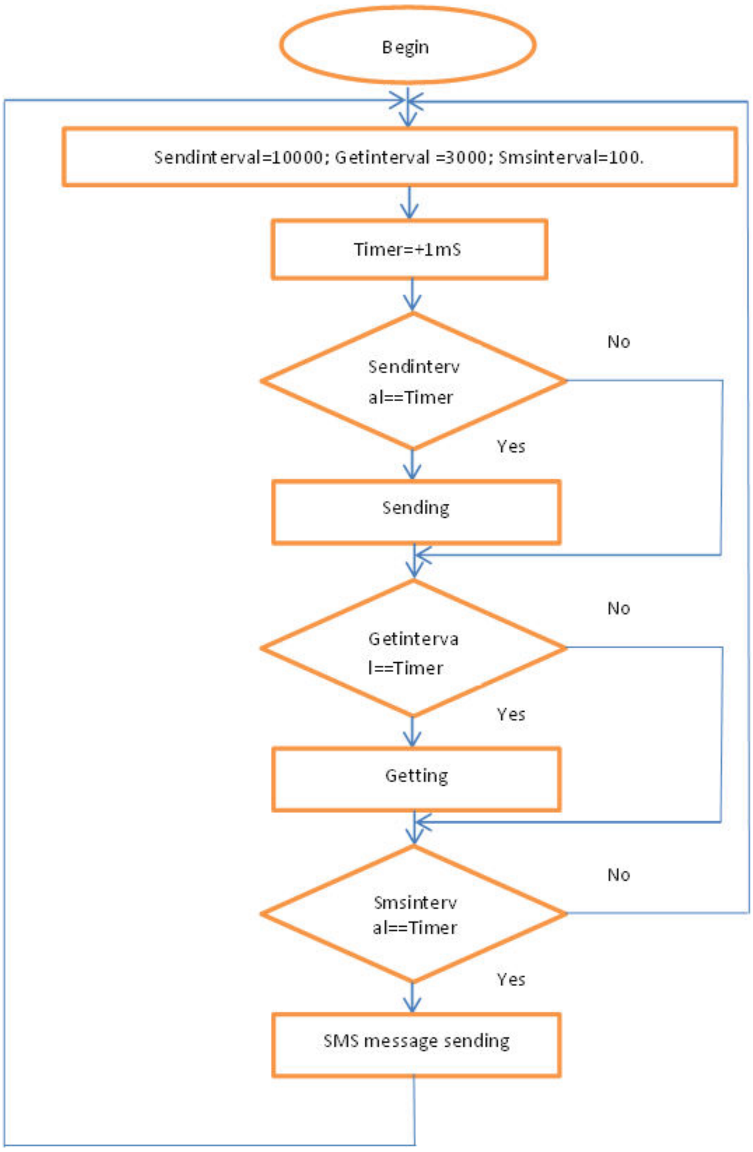

Figure 2.5 - Scheme for SMS-message sending module.

2.3 Use-case diagram

Each type of human-system interaction implies a certain sequence of actions that must be performed by the system at that time. The diagram of use cases (USE-CASE Diagram) is presented below (Figure 3.6)

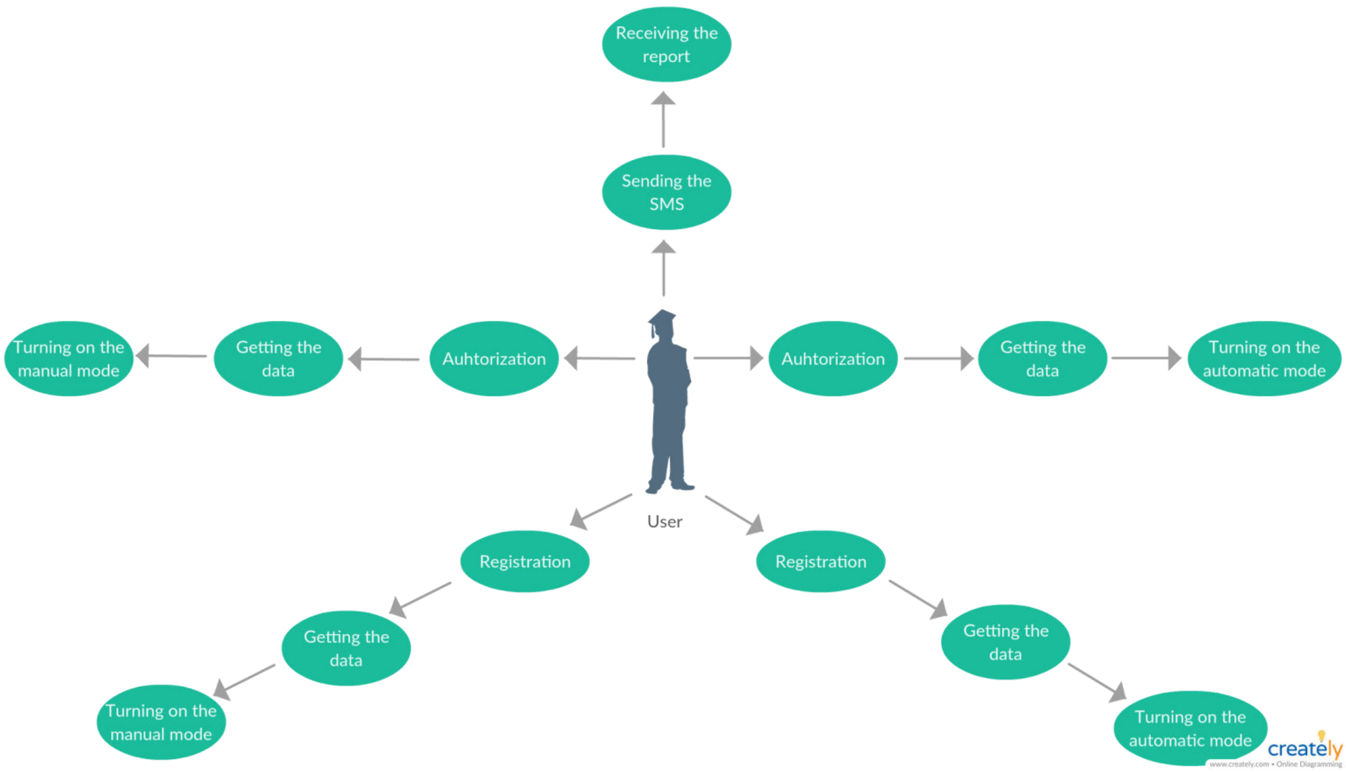

Figure 2.5 - Use Case diagram [3].

Description of the actors:

Actor "User" is able to perform following actions:

- Perform authorization, obtain information about the climate condition, turn on manual control mode,
- Perform authorization, obtain information about the status of the microclimate, enable automatic control mode,
- Perform registration, obtain information about the status of the microclimate, turn on manual control mode,
- Perform registration, obtain information about the status of the microclimate, enable automatic control mode,

– Send SMS requests about the microclimate parameters at the greenhouse and receive an SMS report on the current microclimate conditions.

One of the most interesting options of the system is dual control mode. Microclimate parameters could be controlled by the user manually in the online manual or automated control mode. User can change the parameters setting of the states of the executive mechanisms at the top level of the system. The other type of control implemented in the system – automatic control mode. The main advantage of the method – possibility of independent maintenance of microclimate parameters on the site. User performs setting of the desired microclimate parameters using interface which is situated at the top level of the system once. When all parameters are set, system starts to support these settings. In order to implement this opportunity I have designed table of rules which let the system to obtained desired parameters. The table contains rules for the actuators, changing of the state of the executive mechanisms according to the rules let the system to process changes and perform timely actions to keep parameters at the required level. The further step is implementation of the expert predictive subsystem also at the top level.

2.4 Selecting the programming environment

The development of proprietary software applications based on boards, boards, sensors compatible with Arduino architecture can be carried out in the official free Arduino IDE programming environment as well as in other types of environments and compilers.

To develop and debug the program part of the "Low Level of Automated Climate Control System", the official programming environment of the Arduino IDE was chosen.

Arduino IDE

The Arduino IDE programming environment (Fig. 2.7) is intended for writing, compiling and loading programs into the memory of the microcontroller, which is installed on the Arduino-compatible device board. The basis of this type of development environment is the language of Processing / Wiring - this is actually a normal C ++, supplemented with simple and understandable functions designed to manage I/O on contacts. To date, there are versions of this type of environment for operating systems such as Windows, Mac OS and Linux [4].

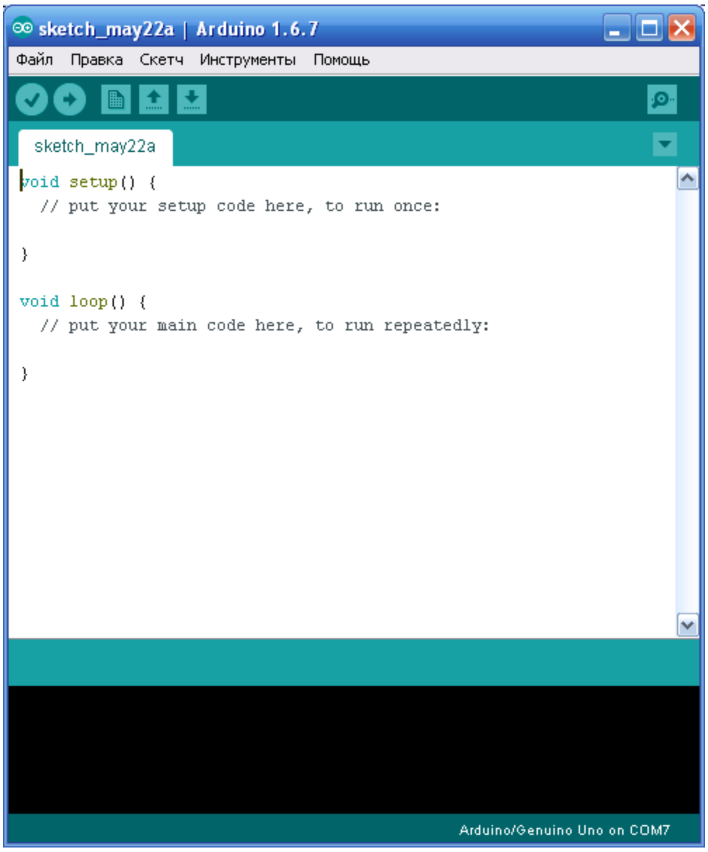

Figure 2.7 - Arduino IDE programming environment.

2.5 Software development

Developing a user interface

There is no user interface on the "Low level", is not presented, it is implemented at the "Top Level" of this system, but without the interface it remains possible to receive an SMS report on the current state of the microclimate parameters at the greenhouse.

Connecting to the server and pseudo parallelism implementing

Connection to the server is performed using the *Ethernet.h* libraries and the functions *begin(mac, ip)* and *connect()*, respectively.

For correct operating of the program and reducing the number of failures, it was decided to implement pseudo-parallelism in the program, it is provided by using the libraries: *Thread.h, ThreadController.h* and accordingly *onRun(sending)* function to send data to the server, *onRun(getting)* to receive commands from the server, *onRun(sms)* for working with SMS messages, all threads work with certain time intervals *setInterval(SENDINTERVAL)* - to send data to the server, *setInterval(GETINTERVAL)* - to receive commands from the server, *setInterval(SMSINTERVAL)* - to work with a stream for SMS messages.

Getting commands from the server

Getting commands from the "Top Level" of the "Automated Microclimate Control System" is performed in the *getting()* function, the *client.avaliable()* client is checked for availability, then the *client.connect(server, 80)* server is connected, where the server-URL of the web- site, 80 - number of the port, followed by checking the commands coming from the website, depending on which control signals are sent to the actuators, the *client.stop()* connection is disconnected at the end, and the *client.flush()* is used to cut off unread bytes at the client's side which were get from the server.

Sending data to the server

To send data to the server *sending()* function is used. At the stage of sending data to the server, similarly to receiving commands from the server, the *client.avaliable()* client's availability is checked, then *client.connect(server, 80)* is connected in the case of client access, where server-URL of the website, 80 - the number of the port, after the connection is established is the sensor poll: *readHumidity()* - getting the air humidity, *readTemperatre()* - getting the air temperature, *analogRead(SENSE1)* and *analogRead(SENSE2)* - getting the soil moisture, transfer the data using *GET* to the server, closing the connection.

SMS messages processing

Checking the incoming message occurs in the *sms()* function, this function checks the availability of GPRS - *gprs.avaliable(),* checks for *codStr.compareTo("Report")*, if the SMS has a code word, then the *sendTextMessage(String ("")), String("User number")*, which polls the air temperature sensors at the greenhouse, the humidity of the air at the facility and the soil moisture at the greenhouse is similar to the *sending ()* function, the SMS message generating and then sending.

2.6 Filtering and processing of the signals from external sensors

During the system's development it was decided to use data from the external air temperature sensors. This approach let us to work with external parameters and allowed to implement predictive expert subsystem at the top level of "Automated Microclimate Control system". To provide data in consentient state it was decided to perform filtering of the input signals from external temperature sensor. To improve the performance of the signals, it was decided to implement filtering to reduce the effect of random interference on temperature measurement.

Any measuring device has a certain error, it can be influenced by a large number of external and internal influences, which leads to the fact that the information from it is noisy. The more noisy the data, the more difficult it is to process such information.

A filter is a data processing algorithm that removes noise and unnecessary information. It was decided to apply filtering based on the Kalman filter.

Using the Kalman filter, it is possible to specify a priori information about the nature of the system, the relationship of variables, and based on this, to build a more accurate estimate, but even in the simplest case (without inputting a priori information), it gives excellent results [5].

Kalman filter uses dynamic model of the system (for example, the physical law of motion), known control actions and a set of successive measurements to form an optimal state estimate. The algorithm consists of two repetitive phases: prediction (2.1), (2.2) and correction (2.3), (2.4), (2.5). The first one calculates the prediction of the state at the next time (taking into account the inaccuracy of their measurement). On the second, new information from the sensor corrects the predicted value (also taking into account the inaccuracy and noisiness of this information) [6]:

Prognosis part:

$$\hat{x}_k^- = F \cdot \hat{x}_{k-1} + B \cdot u_{k-1} \tag{2.1}$$

$$P_k^- = F \cdot P_{k-1} \cdot F^T + Q \tag{2.2}$$

Correction part:

$$K_k = P_k^- \cdot H^T \cdot (H \cdot P_k^- \cdot H^T + R)^{-1} \tag{2.3}$$

$$\hat{x}_k = \hat{x}_k^- + K_k \cdot (z_k - H \cdot \hat{x}_k^-) \tag{2.4}$$

$$P_k = (I - K_k \cdot H) \cdot P_k^- \tag{2.5}$$

Equations are presented in matrix form, and then there will be a simplified version without matrices for the case with one variable. In the case of one variable, the matrices degenerate into scalar values.

Let's look first at the notation: the subscript denotes the time moment: $\hat{x}_k$ is state of system in current moment of time, $\hat{x}_{k-1}$ is state of the system in previous moment of time, $\hat{x}_k^-$ is prediction of the system's state in current moment of time, F is transition matrix between states (dynamic model of the system), B is a matrix of control application, u_{k-1} is control action at a previous point in time, Q is a process noise covariance, P_{k-1} is an error in previous moment of time, P_k^- is prediction of the error, K_k is Kalman gain, H is a measurement matrix representing the ratio of measurements and states, R is a noise measurement covariance, z_k is a measurement in current moment of time, I is an identity matrix.

Let's return to the task of processing data from the temperature sensor, since the state of the system is represented by one variable (air temperature), then the matrices degenerate into ordinary equations (2.6), (2.7) for prognosis part and (2.8), (2.9), (2.10) for correction part.

Prognosis part:

$$\hat{x}_k^- = F \cdot \hat{x}_{k-1} + B \cdot u_{k-1} \tag{2.6}$$

$$P_k^- = F \cdot P_{k-1} \cdot F^T + Q \tag{2.7}$$

Correction part:

$$K_k = \frac{P_k^- \cdot H}{H \cdot P_k^- \cdot H + R} \tag{2.8}$$

$$\hat{x}_k = \hat{x}_k^- + K_k \cdot (z_k - H \cdot \hat{x}_k^-) \tag{2.9}$$

$$P_k = (1 - K_k \cdot H) \cdot P_k^- \tag{2.10}$$

In order to apply the filter, it is necessary to determine the matrices (scalar values in our case) of the variables that determine the dynamics of the system and the measurements of F, B and H:

F is a variable describing the dynamics of the system, in this case it can be the coefficient that determines the temperature change during the sampling time (the time between the steps of the algorithm). For simplicity, it was decided to take this variable equal to 1 (that indicates that the predicted value will be equal to the previous state).

B is a variable defining the application of the control action. If there is any additional information about the influence of the time of day, illumination on the sensor readings, this parameter would determine how the data will change during the sampling time. Since there are no control actions in the model (there is no information on them), then $B = 0$.

H is the matrix defining the relationship between the measurements and the state of the system, this variable also equal to 1.

Defining Smoothing Properties

R is measurement error, which can be determined by testing the measuring instruments and determining the error of their measurement.

Q is definition of process noise is more complex, since it is required to determine the variance of the process, which is not always possible. In either case, you can select this option to provide the required filtering level.

The result of filtering with these parameters is presented in the following figures (Fig. 2.8), (Fig. 2.9), (Fig. 2.10). To adjust the degree of smoothing - user can change the parameters of Q

and R. The R coefficient was determined by testing measuring instrument, Q coefficient was tuned manually to demonstrate different results of the filtering:

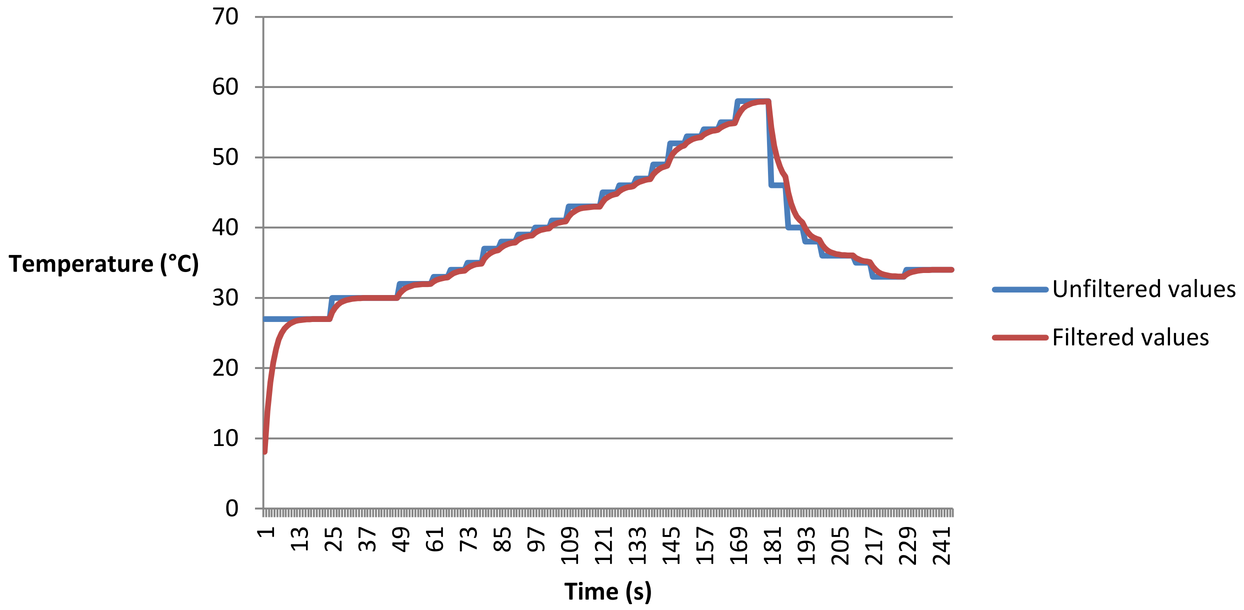

Figure 2.8 - Results of filtering ($R = 1.5, Q = 0.5$).

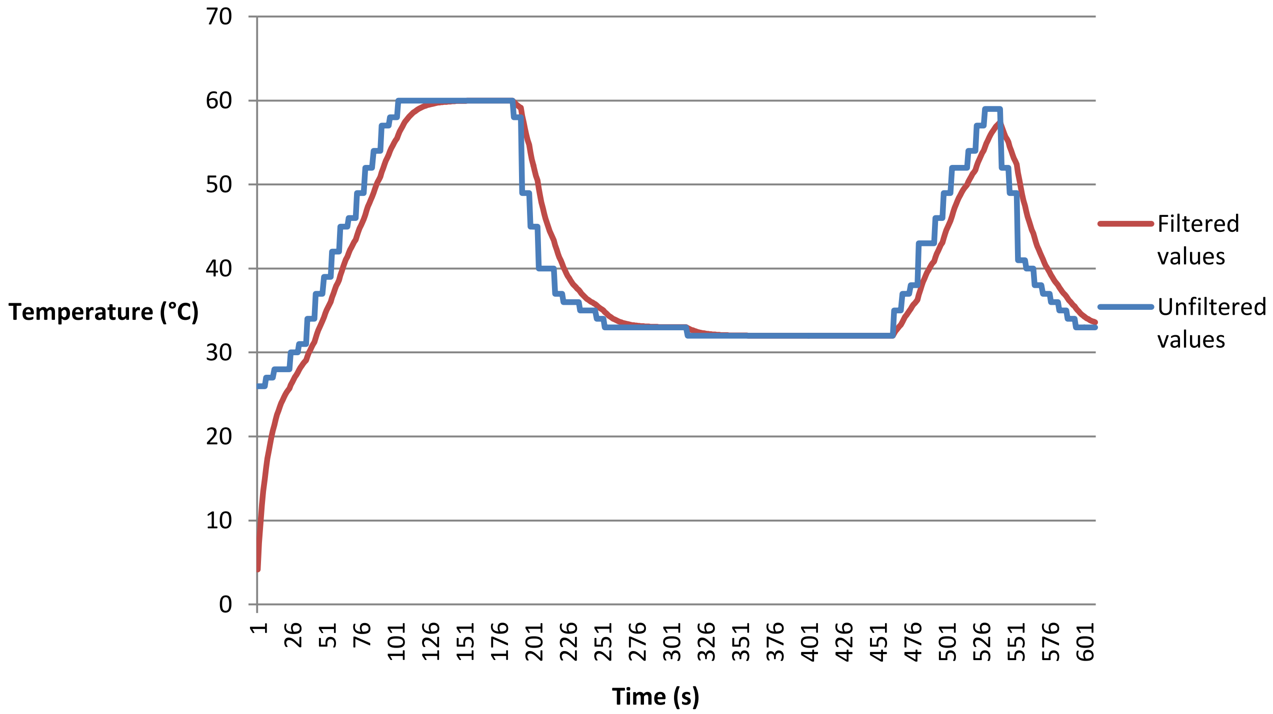

Figure 2.9 - Results of filtering ($R = 5.5, Q = 0.05$).

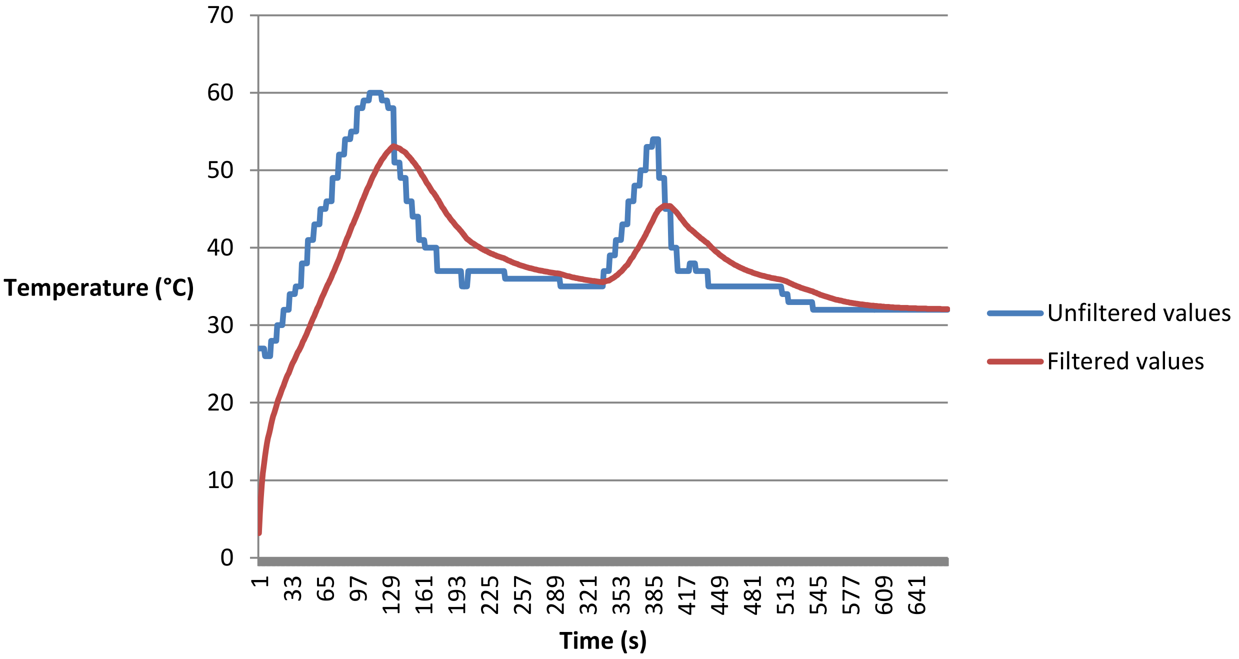

Figure 2.10 – Results of filtering ($R = 7.5, Q = 0.005$).

As can be seen, the relationship between Q and R plays a certain role. $Q \ll R$ leads to strong smoothing and high inertia. $Q \sim R$ leads to decreasing of smoothing.

For further study and improvement of the system's operation, it is planned to apply the filter for several variables, assign a relationship between them, and perform automatic output of values for unobservable variables. Based on this it was decided to use Kalman filter as a base of applied mechanism of filtration, because this type allows to perform following approaches of signal processing, which will help in the process of modernization in future:

- Allows taking into account the dependencies between the parameters (matrix F in the prediction);

- Allows user to take into account the external impact on the system (matrix B in the prediction);

- Automatic selection of the gain depending on the forecast error, and this works well even in the presence of noise;

- As already mentioned before, user can get information about the internal parameters of the system, which, for whatever reason, cannot be measured [7].

3 Testing of the system

3.1 Comparison of the data

In order to test the "Low Level" software of the "Automated microclimate control system", it was decided to modify program code adding part which allows to enable the display of the parameters of interest to us in the monitor of the serial port of the Arduino IDE environment, such as the status of the actuators and the state of the microclimate indicators, received from the sensors at the greenhouse.

To confirm the correct operation of the system, it was decided to perform a comparison of the microclimate indicators on the website (Figure 3.1) and directly on the controller before sending them to the "Top Level"(Figure 3.2)

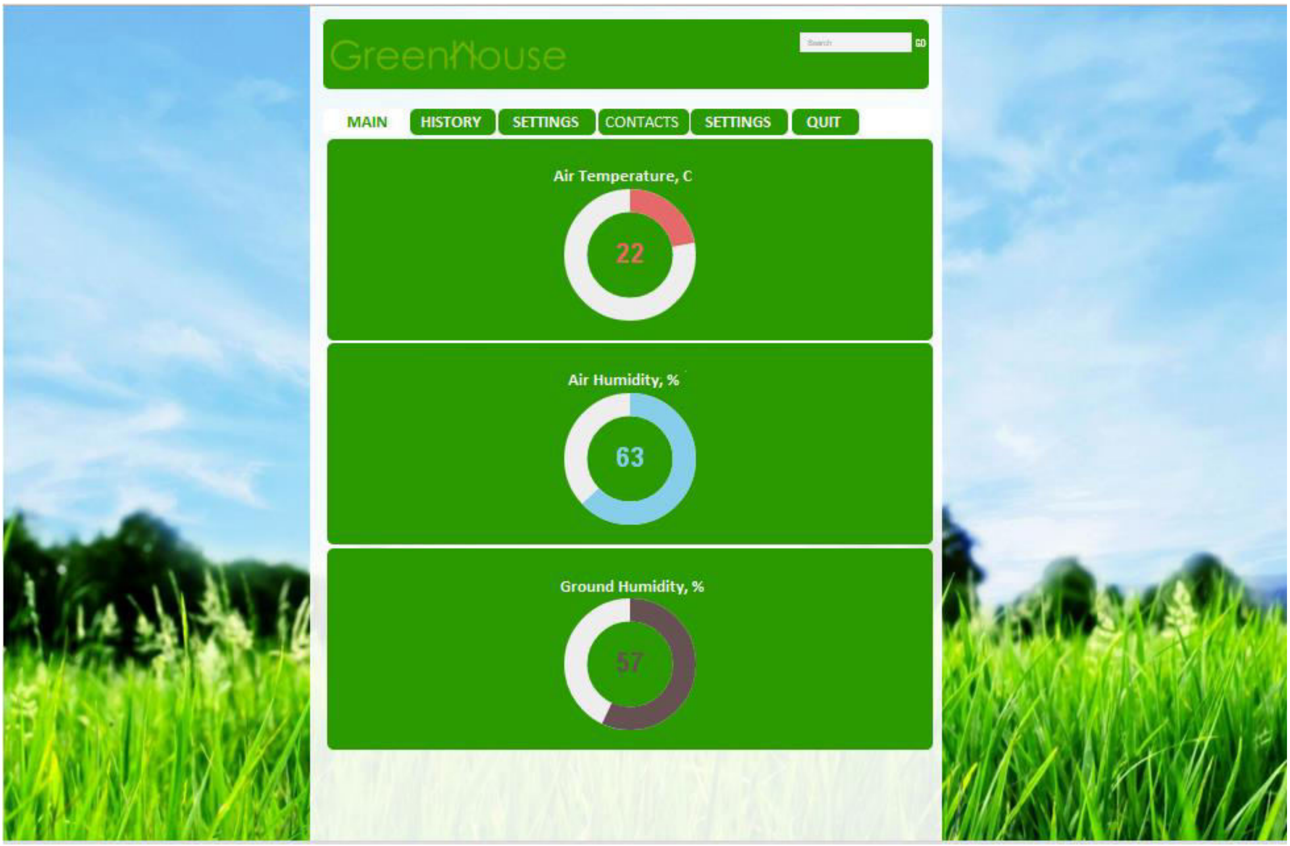

Figure 3.1 - Microclimate parameters at the website (“Top Level”).

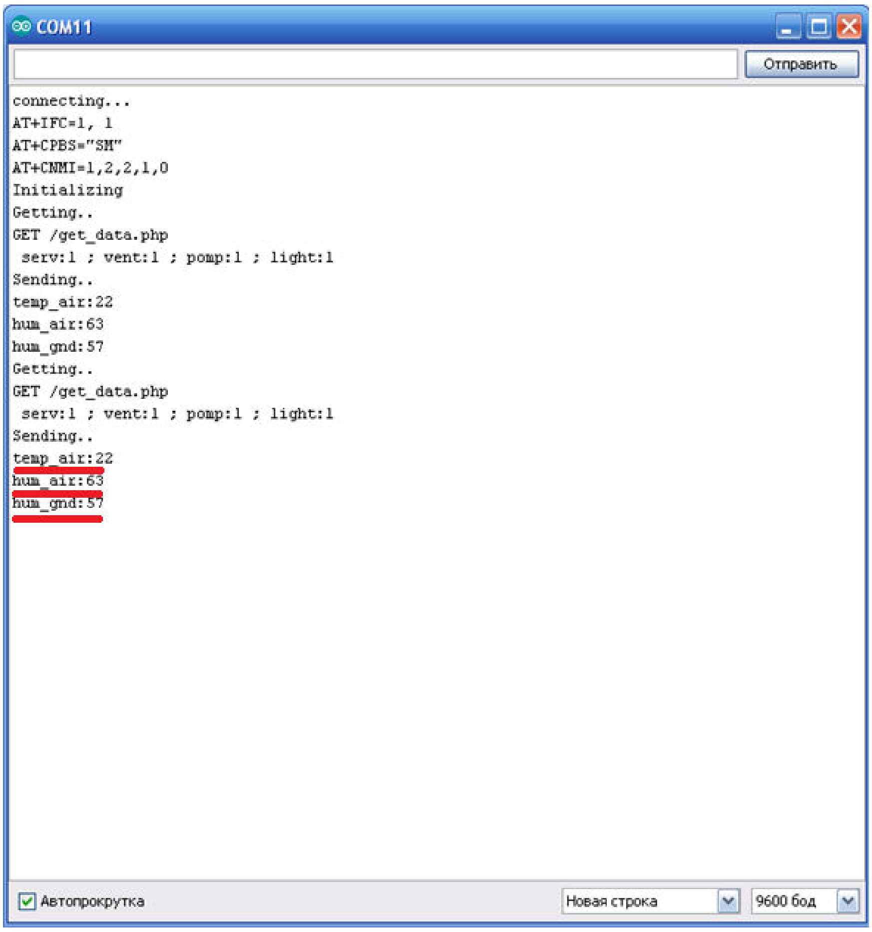

Figure 3.2 - Microclimate parameters at the controller ("Low Level").

To verify the correctness of the operation of the actuators, performing of a similar test by comparing the indicators from the site (Figure 3.3) and the indicators from the controller (Figure 3.4)

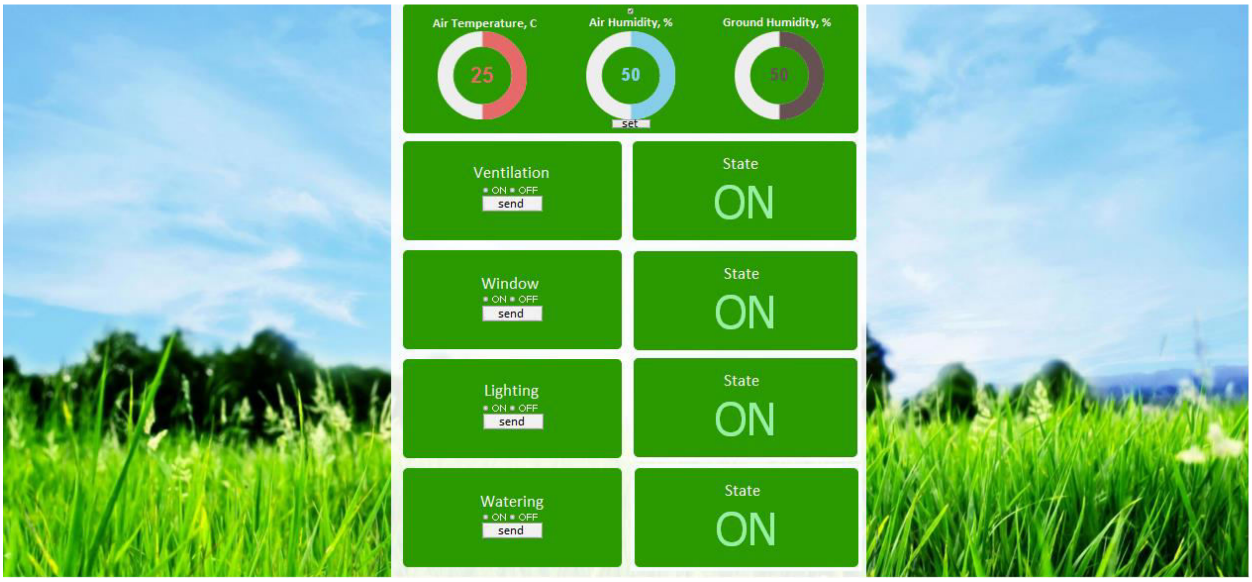

Figure 3.3 - Executive mechanisms state at the website ("Top Level").

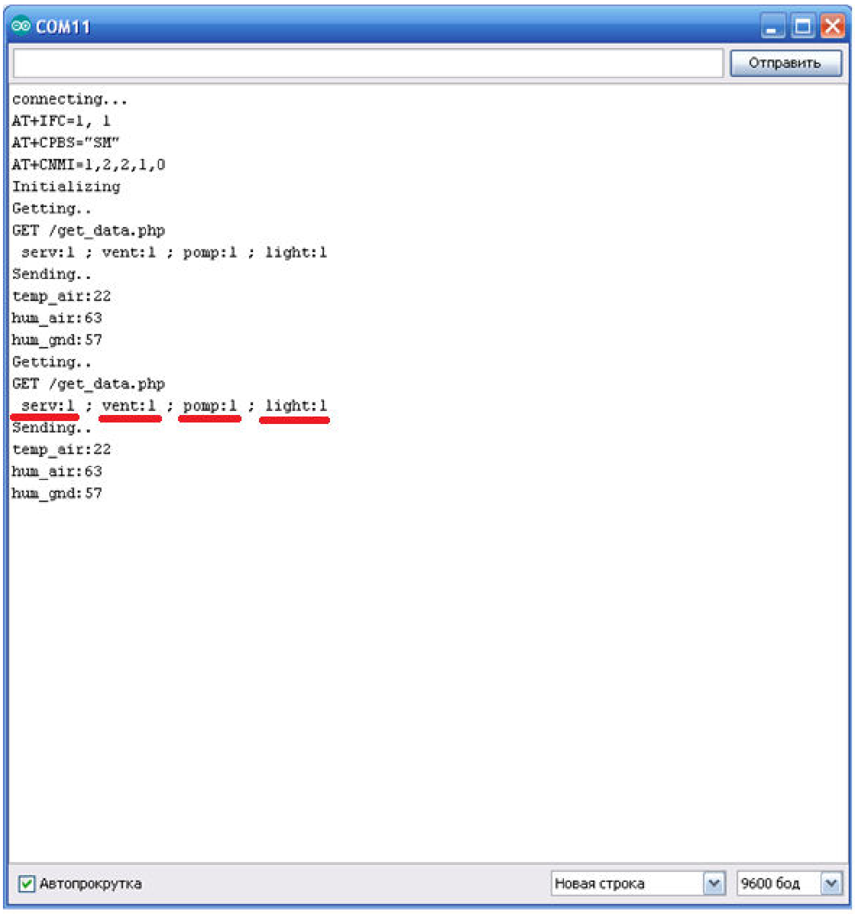

Figure 3.4 - Executive mechanisms state at the controller (“Low Level”).

3.2 SMS informing

Let's also give an example of the SMS function of informing the user (Figure 3.5)

Figure 3.5 - Example of SMS informing of the user.

As could be seen, the results on the website and on the controller coincide, which in general indicates correct and consistent operation of both the system's levels, both low and top. In the test mode, the system worked for about week, during which there were no serious failures and malfunctions, which may indicate good fault tolerance and high reliability of the system.

3.3 Practical value and implementation of the results of work

According to the results of the completed project, it became possible to perform the processing of signals coming from the sensors which are located inside of the object with installed microclimate control system, and from the external set of the sensors. It also became possible to eliminate noise, noise and artifacts during the processing of the incoming signals and transfer them to the upper level of the microclimate control system. For future research it was decided to implement expert predictive system at the top level of the system. This approach will be implemented using artificial neural network. Combination of the expert system and preprocessed filtered values about climate parameters from low level let to improve performance and quality of the system in general.

Another further improvement of the system includes deeper analysis of the data during the system operating period. Based on the results I plan to find out patterns of values variation. This approach in future, provide me with opportunity of improvement of the system, increasing of the preciseness of data processing and prediction of possible changes.

Conclusion

In the course of the master's thesis, software tools were considered. As a means of implementing the project, Processing/Wiring was chosen - this is actually the usual C ++, supplemented with simple and understandable functions designed to manage I/O on contacts. The program was developed on the operating system Windows 10.

Designing of the structure and programming of the corresponding program modules was carried out, as well as testing of their work.

The result of the master's thesis is a software and hardware complex that provides round-the-clock control and management of the processes of growing crops in greenhouse complexes both in manual control mode and in automatic control mode.

The implemented project meets the requirements. User notification via SMS was implemented, which generally increased the reliability of the system and fault tolerance, since in the event of an Ethernet module failure, the user will be able to monitor the microclimate at the site.

The system included ambient temperature sensors, filtering algorithms for the data coming from them for further processing at the top level of the system. This step will allow using of a predictive mechanism for constructing models of possible changes in external parameters. Implementation of the expert system as a whole will increase the effectiveness of the system.

During developing of the mechanism for sending packets with data from the controller to the server, receiving control commands from the server and working with SMS, I have face the problem, due to the inability to perform all three actions simultaneously, which was removed using pseudo-parallelism, for this it was decided to use the Thread.h libraries, ThreadController.h the library data allowed to implement the necessary functionality, as a result, three threads were initialized separately to send data, to receive commands from the website and to work with SMS, each thread has own call time interval.

This solution allowed to avoid overlapping of flows and ensured the correctness of interaction between the low and top levels of the system.

In general, it can be said that the tasks set at the beginning of the performance of the final work on the topic "Development microclimate control unit" successfully implemented, the goal is achieved.

Approbation of work

The results of the research were reported at 3 scientific conferences. Publications: 3 articles were prepared and published.

Publications

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