Wireless Subsystem for Control Technological Parameters of Electrophysical Influence to Increase Plant Productivity

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Abstract.
The article is devoted to the implementation of methods of controlling the functional activity of plants using laser radiation at various stages of organogenesis and their automation. A complex of control and management tools has been developed for conducting experimental studies of modes of electrophysical influence on plant biological objects. In order to receive feedback from plants, a new toolkit for diagnosing the physiological state of plant organisms and a subsystem for monitoring the technological parameters of the plant irradiation process has been developed. A computer-integrated subsystem for monitoring technological parameters for the plant-environment biotechnical system was implemented and implemented in order to increase the productivity of growing vegetable crops. The development was carried out on the basis of a complex of Arduino technical tools and provided for wireless transmission of measured data to the operator's display. The calculation of the distance at which the monitoring subsystem can work to create a connection for wireless data transmission has been performed. The software and hardware of the specified monitoring subsystem are presented. For this purpose, studies of electrophysical methods of controlling the technological parameters of the plant irradiation process and managing their productivity, the main moments of the interaction of laser radiation with biological tissue and the biophysical mechanism were used. The practical application of the research presented in the article can be found in greenhouse farms of Ukraine and other countries, including when growing vegetable crops.

Keywords [1]

Processing of seeds and seedlings, biotechnical system, laboratory installation, laser radiation, automation, monitoring, Internet of things

1. Introduction

Automation of production and increasing the productivity of agricultural crops, in particular vegetables, are important tasks for modern agro-industry. Growing vegetable crops is a complex process that depends on many factors such as climatic conditions, soil conditions, nutrient availability, pests and diseases. Automation of certain processes of growing vegetable crops is a promising direction for the development of agriculture. It allows to increase production efficiency, reduce costs and improve product quality.

One of the important technological processes in the production of rosley is the processing of seeds and plant seedlings for their more intensive growth. Plant processing at different stages of vegetation can affect its quality, the content of useful substances, such as acids, sugars, ascorbic acid, etc. Processing can be magnetic pulse, laser, etc. Magnetic pulse processing, its results and automation of this process are described in articles [1, 2]. The article [1] presents an installation for magnetic pulse

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processing of tomatoes. To maintain the required value of magnetic induction in the zone of influence, the facility design provides for the possibility of changing the position of the working bodies in the vertical and horizontal planes in automated mode. The unit includes a device for magnetic pulse processing of plants, magnetic inductors, a control unit for the adaptation system of working bodies and a program for controlling work modes. As a result of research [2], it was found that the treatment of seedlings and seeds with magnetic pulse treatment significantly affects the physiological loss of tomato mass.

One of the main advantages of laser radiation is that it can be used to improve plant growth and development without the use of chemicals such as pesticides and fertilizers. This can lead to a reduction in the environmental impact of agriculture. In addition, laser radiation can be used to regulate the flowering and fruiting of vegetable crops. This can lead to an increase in the yield and quality of vegetable products. Also, this technology can be used to protect vegetable crops from pests and diseases, which will lead to a decrease in crop losses. One of the prospects is the use of laser radiation to increase the resistance of vegetable crops to stress factors. For example, laser radiation can be used to increase the resistance of plants to drought, frost and pests. Another perspective is to increase the vitamin and mineral content of vegetables to reduce the amount of pesticides and fertilizers used in growing vegetables. Another prospect is the use of laser radiation to create varieties of vegetables that have larger size, better taste, or increased resistance to disease. One of the main challenges is that the laser radiation parameters such as wavelength, power, and exposure time must be precisely controlled for effective laser applications.

2. Literature review

A study conducted at the National University of Singapore [3] showed that laser radiation can increase the growth and yield of tomatoes. Laser radiation with a wavelength of 635 nm and a power of 50 mW was used in the study. Laser radiation was directed at tomato leaves twice a day for 45 days. The results of the study showed that laser radiation increased the height of plants by 15%, and yield - by 10%.

Important in this technology is the development of a new automated system for controlling the impact of low-intensity laser radiation on plants, which will be more effective and economically beneficial.

In Ukraine, during the last decades, there has been a decrease in the profitability of greenhouses, their environmental friendliness, and a decrease in the area of closed soil. This problem is both food and ecological, so there is a need to create high-yielding varieties of plants. To solve this problem, it is necessary to develop automated management systems for biotechnical facilities, in which the enterprise will be a source of information. The information obtained from the vegetation will be a source for choosing optimal control influences. A biological object in the form of a plant is a complex cybernetic system. It is characterized by the possibility of changing both tactics and the optimal management strategy for its adaptation to the environment. Regulation of plant life processes becomes possible as a result of changes in the spatial and spectral distribution of external electromagnetic radiation. A variety of methods, including optical ones, are able to ensure this, as they allow determining the quantitative and qualitative indicators of biological objects with a certain accuracy.

Many researchers in Ukraine and abroad conducted experiments on microclimate management for growing plants in greenhouses and phytotrons. Experiments with the support of the microclimate in growing plants are carried out using a phytotron, for example, as described in the articles of Taiwanese researchers Y.C. Chu & J.C. Chang (2020) [4] and Algerian scientists H.E. Adjerid et al. (2020) [5]. In the article by A. Ouammi et al. (2020). The management of greenhouse parameters based on the Internet of Things (IoT) is presented in an article by Turkish researchers M.A. Akkas & R. Sokullu (2017) [7]. Scientists are creating a personal phytotron at an affordable price thanks to a wide range of equipment, cloud computing and new possibilities offered by the IoT. R.A. Abdelkhahid et al. (2020) [8] investigated that temperature regimes, relative humidity and light as environmental parameters represent regimes for growing seedlings or plants in different developmental phases tested in phytotron chambers. Phytotrons with various electronic control systems are also designed to evaluate the effect of technological parameters on plants for breeding new varieties.

Researchers from Malaysia and Iraq M. Hasan et. al. [9] compared the effects of different laser wavelengths, exposure times, and low-power laser irradiation on maize seeds. Seeds were exposed to red He-Ne (632.8 nm), green second harmonic Nd:YAG laser (532 nm), and diode (410 nm) blue laser. The seed yield was: blue (7003.4 kg/ha) > green (6667.8 kg/ha) > red (6568.01 t/ha) depending on different exposure times of 85 s, 85 s and 105 s respectively according to compared to control 6.9 kg/ha. As a result, the possibility of using blue laser light to control the growth and yield of corn has been proven.

Researchers from Pakistan Asghar, T. et al. [10] assessed the effects of pre-sowing seed treatment with laser and magnetic field on soybean sugar, protein, nitrogen, hydrogen peroxide, ascorbic acid, proline, phenol, malondialdehyde and also chlorophyll. The effects of both treatments (laser and magnetic field) were significantly higher compared to the control (untreated seeds). The results showed that pre-planting laser and magnetic field treatment of seeds potentially improved soybean biological fragments, chlorophyll content and metabolically important enzymes (decomposes stored food and removes reactive oxygen species).

Cuban researchers A. Álvarez et al. (2011) [11] investigated the effect of seed treatment with low-power laser radiation on some physiological parameters and yield of tomato hybrid NA3019 in protected growing conditions. The seeds were irradiated with a He-Ne laser with a power of 25 mW at different exposure periods: 5, 10, 20, 30 and 60 seconds. The results showed a significant increase ($p \leq 0.05$) in plant height (50%), root length (13%), stem diameter (17%), equatorial average diameter (7%), average fruit weight (13%) and yield from the plant (67%), compared to untreated seeds. This confirms the stimulating effect of low-power laser radiation on the growth and yield of plants, in particular, tomatoes.

In the article L. Nykyforova et al. (2022) [12] presented the processes in crop production as a biotechnical system, and also presented a scheme of a computer-integrated plant productivity management system based on an Arduino integrated board.

The purpose of this study is to increase the efficiency of growing seedlings and seeds through the use of electrophysical methods of influencing plants, as well as the development and experimental verification of a wireless computer-integrated plant productivity management system.

To achieve this goal, the following tasks were set:

- analyze the connection in the plant-environment biotechnical system;
- develop the structure of experimental research;
- create an algorithm for remote measurement of temperature and power of laser radiation;
- carry out the technical implementation of the technological parameter monitoring subsystem for this biotechnical system, where wireless transmission of measured data is provided.

It is proposed to improve the system of automated control of parameters of the biotechnical system "plant-environment" by adding a subsystem for monitoring technological parameters, which will measure the temperature and power of laser radiation.

The above, based on measurements, will allow to improve existing automated control systems for the formation of control action during seed germination and seedling growth. At the same time, the control action will be formed for each installation (thermostat, phytocamera, etc.) and will provide further analysis of the production of the considered biotechnical system as a whole.

3. Materials and methods

The research used a mathematical corrective model of the interaction of laser radiation with solid biological tissue (L. Nykyforova et al., 2023) [13].

In the case when it is necessary to describe the process of action of high-energy laser radiation on solid biological tissue, it is necessary to take into account the processes of temperature distribution. Evaporation of biological tissue occurs at a temperature above 300 °C. Therefore, the amount of heat entering the area of the biotissue should heat it up to a temperature above 300 °C. For calculations of this process, the general spatio-temporal characteristic of the temperature distribution described in [13] was used.

In addition, the refractive index R and transmittance are constant for this biological tissue. The relationship according to the Lambert-Behr equation works when the absorption of light significantly exceeds its scattering. The mechanism of light absorption depends on the concentration of light-absorbing molecules, the amount of absorption at the cellular and subcellular levels can differ significantly for different molecules. In addition, the absorption coefficient may differ for lasers operating in different spectral ranges due to the fact that absorption is a function that depends on wavelength.

In the range from 600 to 1200 nm, light penetrates more widely into biological tissue with minimal effects on absorption and scattering. In this range, radiation can reach deep molecular layers. Laser devices such as argon, dye, IAG (aluminum-yttrium garnet): Nd laser (both conventional and frequency-doubled) strongly affect hemoglobin, melanin and other organic substances, and may also have a coagulation effect. The mathematical model [13] is best suited to describe the process of lithotripsy, when biological tissue is removed. It allows you to determine the depth of the hole formed by the laser beam

To carry out physiological measurements of seed treatment with a low-energy non-monochromatic field, the following technical support was used: device for seed treatment (laser research complex with nozzles of different wavelengths, thermal camera TS-20, electric field power meter, temperature sensor in the phytotron, computer and network equipment , which together form a single optical-electronic technical system of research and express diagnostics of the state of plants.

Figure 1 shows the structural diagram of laboratory equipment for processing seeds in a thermal chamber and plants in a phytotron with a low-energy non-monochromatic field. Laser treatment of plants can take place at different stages of vegetation, such as seed germination in a thermal chamber and growing seedlings. At the same time, the temperature, power of laser radiation, and bioelectric potential (impedance) of the plant are controlled in the research.

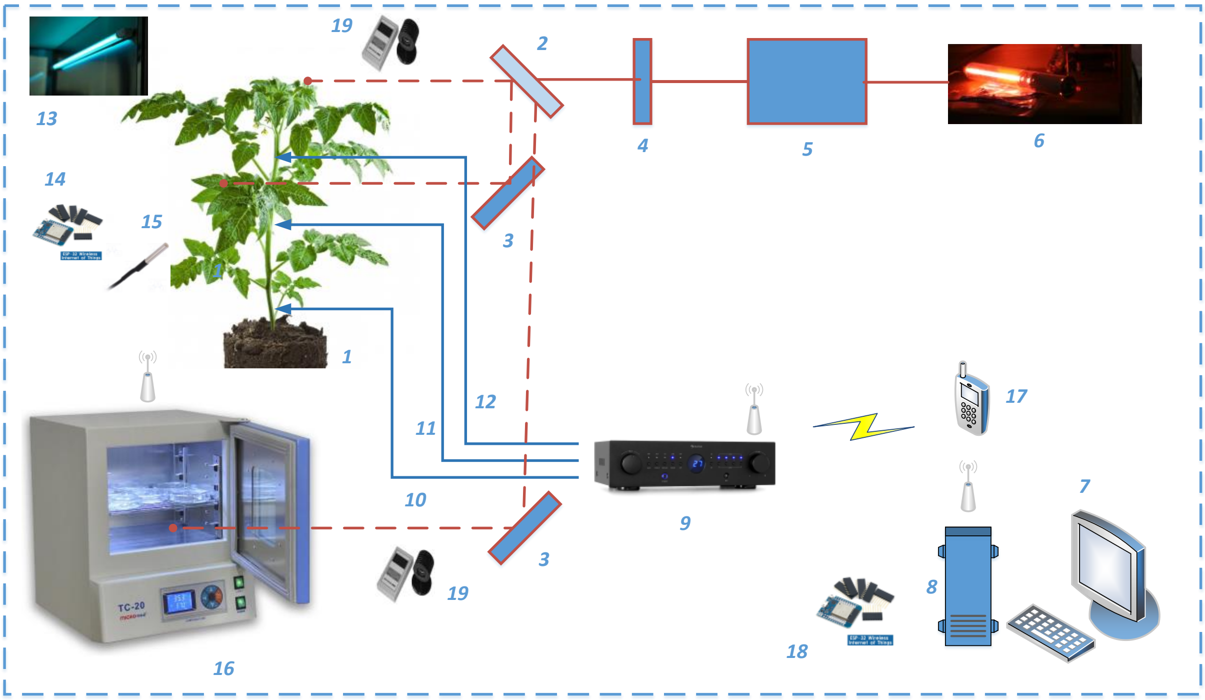


Figure 1. Scheme of the experimental setup. 1 - plant; 2 - translucent plate, 3 - mirror, 4 - aperture, 5 - polarizing filter; 6-source of local radiation (He-Ne laser); 7 - Faraday cage; 8 - recording device; 9 - multichannel amplifier, 10 - reference electrode, 11, 12 - measuring electrodes; 13 - source of non-local radiation (fluorescent lamp Radium); 14 - wireless transmitter board; 15 - temperature sensor; 16 - thermostat for seed germination; 17 - smartphone; 18 - wireless receiver board; 19 - laser power meter.

Control of the functional activity of plants by coherent light is described by J. Chávez et al. (2018) [14]. In particular, the methodology, analytical equipment and technical means of studying the interaction of coherent light with biological systems and structures have been developed, the block-modular principle of designing laser installations and diagnostic devices for crop production has been proposed and developed. The work presents experiments on the irradiation of both seeds and ripe fruits. In the researches, multifunctional devices of the LIK series (laser research complex) and production devices of the VOC series (agricultural laser irradiator) were used, and a control system for this device was developed. The control block diagram is given in [14]. and includes three units connected by electrical signals: BUCF (work control and management unit), BOS (radiation object feedback unit) and BFPI (irradiation flow forming unit).

The most modern apparatus for laser irradiation, which we use in our research, is Lika-Led (PP "Fotonika-plus", Cherkasy, Ukraine) [15]. Development and implementation of a phytomonitoring system of technological parameters of growing in a phytotron and the possibility of remote switching of connected devices of the electrical complex.

The set of devices for measuring the optical parameters of fiber-optic lines and the power of laser radiation consists of a power meter (IM-3) and a Lika-Led electronic unit with a set of laser modules. The device allows measuring the optical power of laser radiation in a wide spectral (from 400 nm to 10.6 μm) and energy (from 0.05 W to 30 W) ranges. In addition, the design of the device allows you to work with each wavelength or several wavelengths at the same time. The radiation is combined using a laser radiation combiner.

The device provides:

- measurement of optical power of laser radiation;
- stepwise regulation and control of radiation power;
- establishment and control of procedure time;
- radiation modulation;
- radiation dose control;
- simultaneous operation of 4 laser modules.

The device is equipped with a "Touch screen" touch panel. Lika-Led device settings are shown in fig. 2. To calculate the data transmission distance, calculations were made to determine the distance of the wireless connection of the complex operation and attenuation in free space [16].

Free-space path loss (FSPL) is the attenuation of radio energy between the feed points of two antennas, which is the result of the combination of the receiving antenna's capture zone and the obstacle-free line-of-sight path through free space (usually air). The calculation is carried out according to the following formula, which is derived from the Fries transfer formula [16]:

$$\frac{P_r}{P_t} = D_t\, D_r \left(\frac{\lambda}{4\pi d}\right)^2, \tag{1}$$

where $P_r -$ received radio wave power, dBm; $P_t -$ transmitted power, dBm; $D_t -$ directivity of the transmitting antenna, dBi (decibel isotropic); $D_r -$ this is the directivity of the receiving antenna, dBi; $\lambda -$ wavelength, m; d – distance between the receiving antenna and the transmitter antenna, m.

Since attenuation in free space is a loss coefficient that depends on distance and wavelength, if we assume that the antennas are isotropic and have no directionality, then (1) can be represented in the following form:

$$FSPL = 10\ \log_{10}\left(\left(\frac{4\pi d}{\lambda}\right)^2\right). \tag{2}$$

where *FSPL* - attenuation in free space, dB (decibels) [17].

At the same time, the wavelength is equal to:

$$\lambda = \frac{U}{f}, \tag{3}$$

where *U* – speed of radio wave propagation (U = 299,792,458 m/s) [17], *f* - operating frequency of the radio module, GHz.

The distance between the receiving antenna and the transmitter antenna will be equal to:

$$d = \frac{4\pi}{\lambda}\sqrt{\frac{P_t}{P_r\, D_t\, D_r}}, \tag{4}$$

Antennas are isotropic, then:

$$d = \frac{4\pi}{\lambda}\sqrt{\frac{P_t}{P_r}}, \tag{5}$$

According to the nRF24L01 data sheet, P_r = - 85 dBm (decibel - milliwatt), P_t = -18 dBm, f = 2.4 GHz From here:

$$\lambda = \frac{299\ 792\ 458}{2{,}4*10^9} = 0{,}125 \text{ м.}$$

Then:

$$d = \frac{4\pi}{0{,}125}\sqrt{\frac{-18}{-85}} = 46{,}294 \text{ м.}$$

Extinction in free space:

$$FSPL = 10\ \log_{10}\left(\left(\frac{4\pi * 46{,}294}{0{,}125}\right)^2\right) = 73{,}35 \text{ дБ}$$

Figure 2. Setting up the Lika-Led device

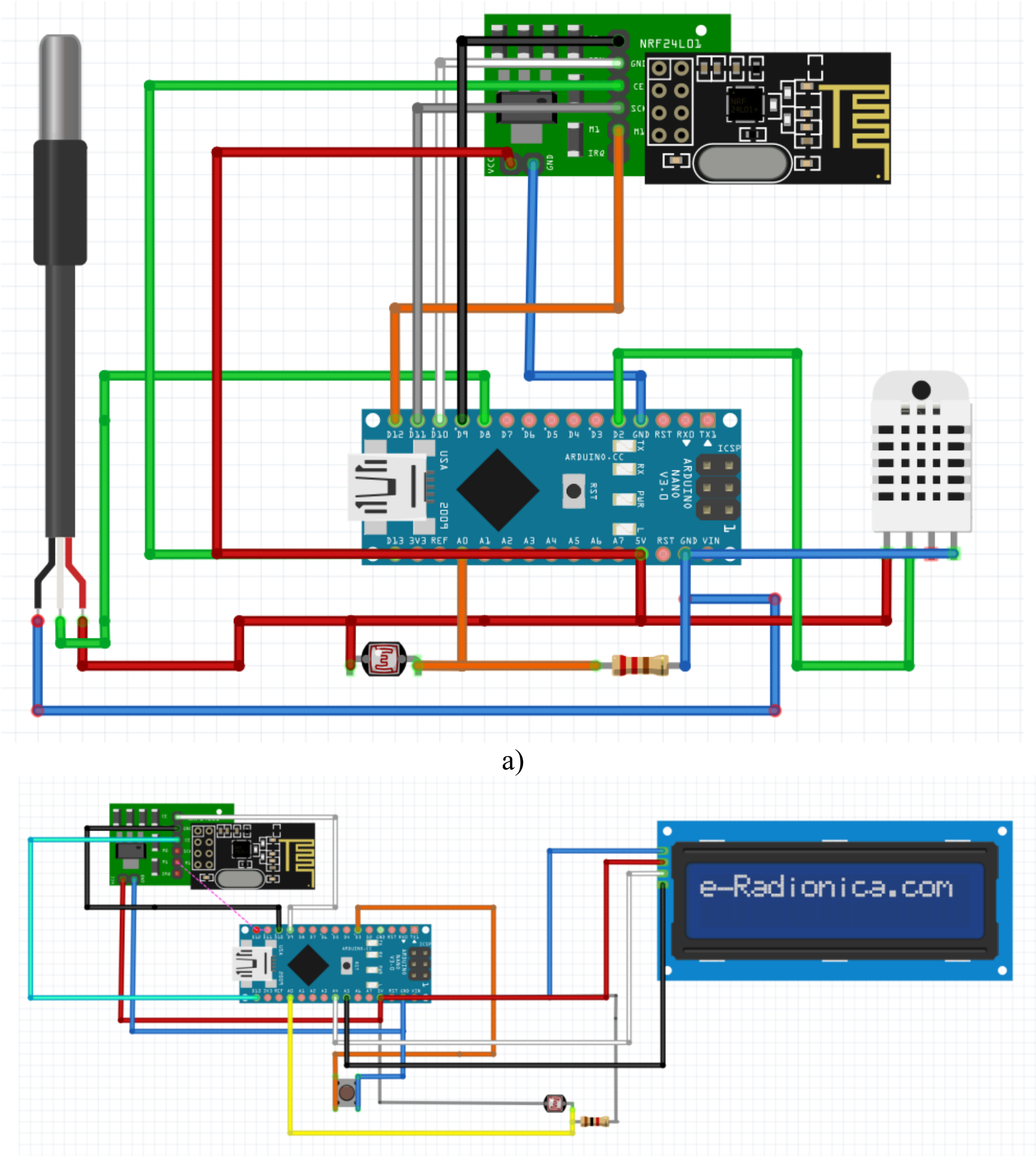
4. Results

The mnemonic diagram of the developed subsystem is shown in fig. 3. The hardware part of the subsystem includes:

- measuring elements (fermentation medium temperature sensors, air temperature sensors, air humidity sensors, light level sensors);
- data transmission elements (wireless data transmission modules);
- control device (microcontroller);
- elements for human-machine interaction (displays, buttons).

In turn, the solution to the problem of bulky equipment was the use of wireless communication directly between the sensing elements of the monitoring system (SM) and the main microcontroller, which processes and displays information in an accessible form. Arduino Nano R3 programmable devices perform the function of microcontrollers that collect and process information. Arduino Nano is a full-featured miniature device based on an ATmega328 microcontroller with a clock frequency of

16 MHz. The Arduino Nano platform included: 22 digital contacts (6 of which can be used as pulse width modulation), 8 analog input contacts, 2 input contacts for serial interfaces (UART) [18], a mini-USB port, with the SPI protocol [19] and the reset button.



a)

б)

Figure 3. Mnemonic diagram of the technological parameter monitoring subsystem: a - transmitter; b - receiver

Monitoring is implemented with the help of electrical sensors, which, depending on the nature of the execution, have different types of output signals - analog and digital. Appropriate sensors were selected for measuring the necessary parameters:

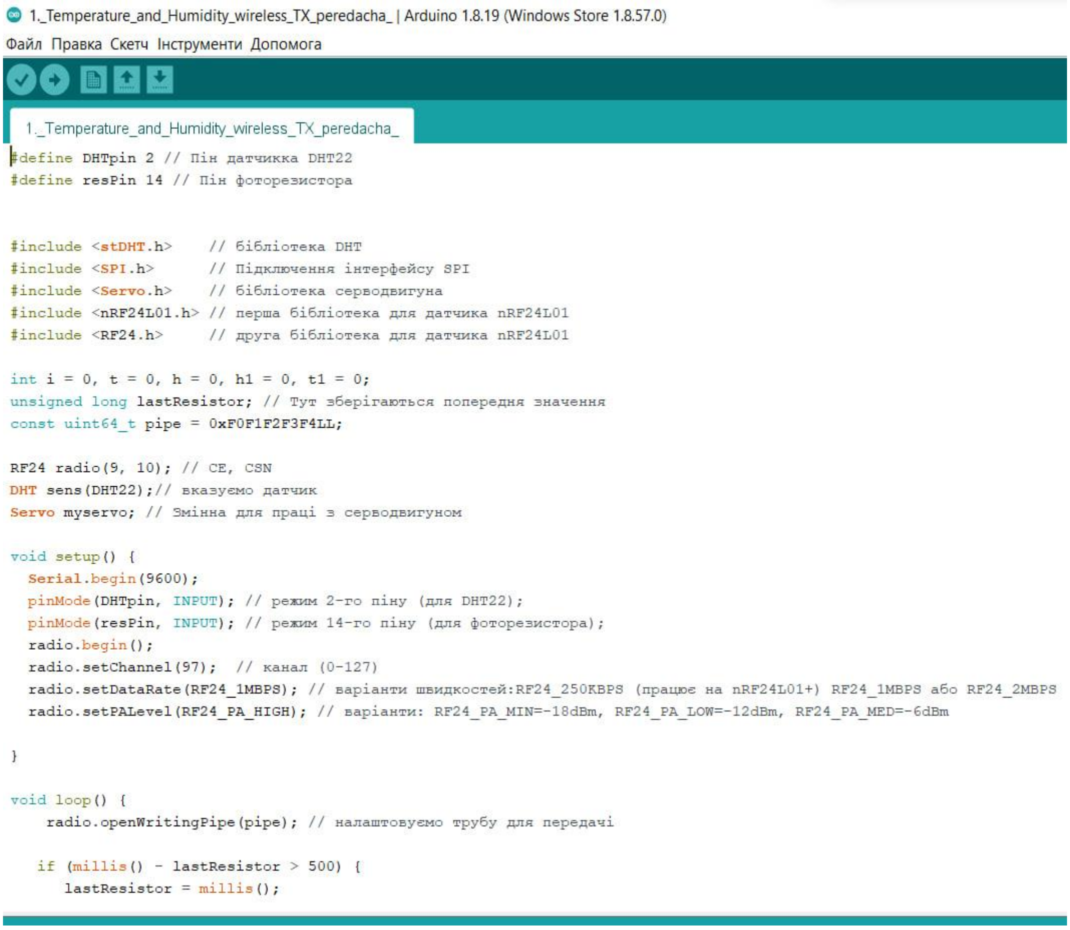
- air temperature and humidity (sensor type DHT22) [18];
- lighting (photoresistor GL5528) [20];
- temperature sensor (DS18B20 waterproof).

The data transmission function from the transmitters to the receiver is implemented using the nRF24L01 wireless communication module with a communication frequency of 2.4 GHz [21]. The complex, which was described above, is programmed in the Arduino IDE software package [18]. The following libraries were used when creating the program text:

- stDHT.h – library for controlling the DHT22 sensor;
- SPI.h – a library for activating and using the SPI bus;
- nRF24L01.h and RF24.h – libraries for connecting and controlling the nRF24L01 module;

- LiquidCrystal_I2C.h – a library for connecting and controlling liquid crystal displays via the I2C bus [18];
- microDS18B20.h – a library for connecting and reading data from the DS18B20 sensor.

A fragment of the program text is shown in the Arduino IDE environment in Fig. 4.



```
#define DHTpin 2 // Пін датчикка DHT22
#define resPin 14 // Пін фоторезистора


#include <stDHT.h>     // бібліотека DHT
#include <SPI.h>       // Підключення інтерфейсу SPI
#include <Servo.h>     // бібліотека серводвигуна
#include <nRF24L01.h> // перша бібліотека для датчика nRF24L01
#include <RF24.h>      // друга бібліотека для датчика nRF24L01

int i = 0, t = 0, h = 0, h1 = 0, t1 = 0;
unsigned long lastResistor; // Тут зберігаються попередня значення
const uint64_t pipe = 0xF0F1F2F3F4LL;

RF24 radio(9, 10); // CE, CSN
DHT sens(DHT22);// вказуємо датчик
Servo myservo; // Змінна для праці з серводвигуном

void setup() {
  Serial.begin(9600);
  pinMode(DHTpin, INPUT); // режим 2-го піну (для DHT22);
  pinMode(resPin, INPUT); // режим 14-го піну (для фоторезистора);
  radio.begin();
  radio.setChannel(97);  // канал (0-127)
  radio.setDataRate(RF24_1MBPS); // варіанти швидкостей:RF24_250KBPS (працює на nRF24L01+) RF24_1MBPS або RF24_2MBPS
  radio.setPALevel(RF24_PA_HIGH); // варіанти: RF24_PA_MIN=-18dBm, RF24_PA_LOW=-12dBm, RF24_PA_MED=-6dBm

}

void loop() {
    radio.openWritingPipe(pipe); // налаштовуємо трубу для передачі

   if (millis() - lastResistor > 500) {
      lastResistor = millis();
```

a)

Figure 4. A fragment of the program text in the Arduino IDE environment: a) transmitter; b) receiver.

5. Discussion

When analyzing the connection in the plant-environment biotechnical system, material and information channels were selected, a set of input and output state parameters was determined, as well as the nature of direct and cross connections, sources of external disturbances were identified in the work [13]. There, a parametric model of the plant biosystem is prepared, the most significant material and information flows that require monitoring and analysis are highlighted

Optimizing energy costs for growing vegetables in greenhouses is presented in an article by Canadian researchers M.C. Bozchalui et al. (2015) [22]. The developed monitoring system based on a wireless sensor network of a greenhouse using solar energy is described in an article by Chinese researchers J. Hou & Y. Gao (2010) [23]. An energy-efficient greenhouse based on renewable sources of electricity is presented in the article by Romanian researchers R. Grihoriu et al. (2015) [24]. Similar computer-integrated systems were implemented by the authors for a phytotron, a feed store and a livestock room (N. Kiktev et al., 2021) [25]. The use of cloud intelligent technologies and the mathematical apparatus for this are described in the articles [26-28].

In recent years, publications have appeared on the study of laser effects on plants and seeds. Scientists from Saudi Arabia, Egypt and Belgium M.K. Okla et al. (2021) [29] wrote about the effect of laser irradiation of lemongrass seedlings, namely on the improvement of biomass photosynthesis, chemical composition and biological activity. The authors found that laser light improved photosynthetic activity, respiration, and thus seedling wet weight. Polish researchers A. Klimek-Kopira and others. (2020) [30], J. Dłużniewska and others. (2021) [31] evaluated the productivity and health of soybean plants as a result of coherent irradiation of seeds together with irradiation of fungal inoculum, which showed a reduction in plant disease of this crop. The authors determined the best wavelength for laser irradiation, which was 514 and 632.8 nm.

```
#define DHTpin 2 // Пін датчикка DHT22
#define butPin 3 // пін для кнопки
#define servoPin 4 //  Пін для серво
#define soundPin 5 // пін для п'єзо
#define relayPin1 6 // Пін реле 1
#define relayPin2 7 // Пін реле 2
#define relayPin3 8 // Пін реле 3
#define resPin 14 // Пін фоторезистора

#include <SPI.h>
#include <stDHT.h>    // бібліотека DHT
#include <nRF24L01.h>
#include <RF24.h>
#include <LiquidCrystal_I2C.h>
#include <Servo.h>   // бібліотека серводвигуна

RF24 radio(9, 10);
DHT sens(DHT22);// вказуємо датчик
LiquidCrystal_I2C lcd(0x27, 16, 2);
Servo myservo; // Змінна для праці з серводвигуном

int scrollFlag = 0, t0, h0, i0, t, h,i, t1, h1, i1, percentValue;
volatile boolean button = 0,button2, buttonFlag = 0,buttonFlag2, counter = 0, counter2 = 0,servoCounter;
int buttonState = 0, lastButtonState = 0; // Текущее состояние кнопки
unsigned long lastDebounceTime = 0, longPressDuration = 3000, lastSD, lastResistor, lastScroll, lastRight, lastLeft, lastSound, lastButton;;
const uint64_t pipe = 0xF0F1F2F3F4LL;
byte delta[8] = {B00000, B00100, B01010,B01010, B10001,B10001, B11111,B00000}; // Код символу дельта

void setup() {
  Serial.begin(9600);
  lcd.init();
  lcd.backlight();
  lcd.home();
  radio.begin();
```

б)

Figure 4 (continue)

6. Conclusions

The functionality of the developed subsystem allows measuring technological parameters in the system of electrophysical influence on plants. In the future, with the help of Internet of Things technology, the information will be transferred to a specified server for the operator and further analysis of the production process. The software and hardware support of the technological parameter monitoring subsystem for the bioenergy complex, where wireless data transmission is provided, has been developed. The free-space attenuation and data transmission range were calculated to be 73.35 dB and 46.294 m, respectively. Testing was carried out in laboratory conditions.

Based on the described results, a plant development study model was implemented. A plant productivity management system based on electrophysical methods was developed and researched using a modern LIKA-LED laser radiation device of different frequencies. The structure of the laboratory installation and control system was developed, an algorithmic control block diagram was built, and a phytomonitoring system of plant growing parameters using wireless computer-integrated technologies was implemented.

In the future, the development of the project is planned, namely: the use of a modern LIKA-LED laser radiation device of different frequencies and its inclusion in the scheme of the developed computer-integrated system. In further studies, it is also planned to analyze the effect of different wavelengths of laser radiation on the growth of seeds and seedlings of vegetable crops.

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