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Capabilities of microclimate parameters control with the use of embedded system

Introduction

Crop production in an artificially created environment depends on many factors that affect their normal growth. A suitably selected light, temperature, air, soil, humidity and water are needed to setting up an appropriate microclimate. None of these factors can lead to a stop in the growth of a plant or to an increase in susceptibility to various diseases. It is necessary to recreate environmental conditions similar to the natural, in which plants exist, in order to provide the right climate for the growth of plant (Mynett 1990).

The light, which is a kind of electromagnetic energy arising in the conversion of matter particles emitting the energy as a result of heat up, a chemical reaction or other causes, affects the processes occurring in the plant (Halliday et al. 2001).

All processes connected with growth of plants are indirectly controlled by light of various kinds. The plant can be stimulated and vegetation can be accelerated through light energy, which is used in the process of photosynthesis and photomorhogenesis (Puternicki, Lisak, Treder et al. 2012). As light-dependent, the process of photosynthesis includes photochemical reactions, in which light energy is absorbed by the chlorophyll and carotenoids in the leaves of plants. Energy, which is produced in this way, is used, inter alia, to form sugars from carbon dioxide absorbed through the leaves. Pigments of chlorophyll "a" and "b" absorb particularly well chosen frequency from energy spectrum of light radiation (Fig. 1) (Puternicki, Lisak, Treder et al. 2012; Kopcewicz, Lewak 2002).

Light affects the growth of plants, irrespective of photosynthesis and photomorhogenesis. Light is the primary external factor necessary for the stimulation of all processes in the plant during the vegetative growth cycle. Light is a factor influencing transformation of matter into energy. In order to quantum of light to be absorbed, it must have a wavelength suitable for absorbing it by a photoreceptor (Halliday et al. 2001; Kopcewicz, Lewak 2002).

Photoperiodism determines the speed of plant growth and productivity as well. Plants grow mostly at night, and therefore plants illuminated for too long remain low and produce small leaves. Too dimly lit plants pull their fragile stems in search of light (Mynett 1990; Puternicki, Lisak, Treder et a.l 2012).

A proportional increase in individual elements of the plant, as well as a correct colour of plants proves that they are optimally illuminated. The requirements on light demand of plants grown indoors are very different. The requirements correspond to light conditions in which plants use natural occurrence in the environment. Therefore, it is important to choose the appropriate light intensity and photoperiod, so that the plant obtains proper conditions to the correct growth and stable operation of the biological clock (Mynett 1990; Puternicki, Lisak, Treder et al. 2012).

In favourable conditions, in temperate climates in the summer sun in diurnal cycle is approximately 14 – 15 hours (Fig. 2). This is a time exceeding the saturation level in plants. However, in months of late autumn and winter, the amount of light per day drastically drops to 8–9 hours. At this time, the plants are poorly lit, which directly affects their growth (Puternicki, Lisak, Treder et al. 2012).

Cultivation of plants under artificial light is designed to create optimal conditions at any stage of growth, from vegetation to the formation of flowers and fruits. Insufficient amount of light can cause a slowdown or adversely affect the development of morphogenetic plant, resulting in a slender, excessively elongated stem. Such conditions often lead to a reduction in productivity of the plant. Energy efficiency and radiation spectrum are important when selecting a light source.

All photobiological processes taking place in the plant are reflected both in the radiation intensity and spectral distribution of the radiation delivered to the plant (Puternicki, Lisak, Treder et al. 2012).

Insufficient amount of light directly affects the growth and flowering of plants. A suitable light source supports the cultivation in artificially created conditions and makes cultivation more efficient. A luminous efficiency, durability, and spectral distribution of the radiation are factors which can determine the choice of a light source ((Puternicki, Lisak, Treder et al 2012; Gajc-Wolska, Kowalczyk, Hemka et al. 2010; Klamkowski, Treder, Treder et al. 2012; Żupnik, Grzesiak et al. 2012).

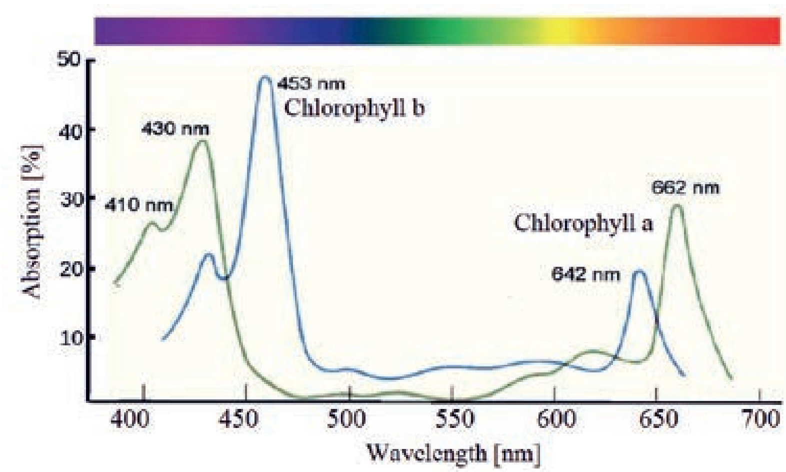


Fig. 1. The absorption spectra of photosynthetic pigments chlorophyll "a" and "b"

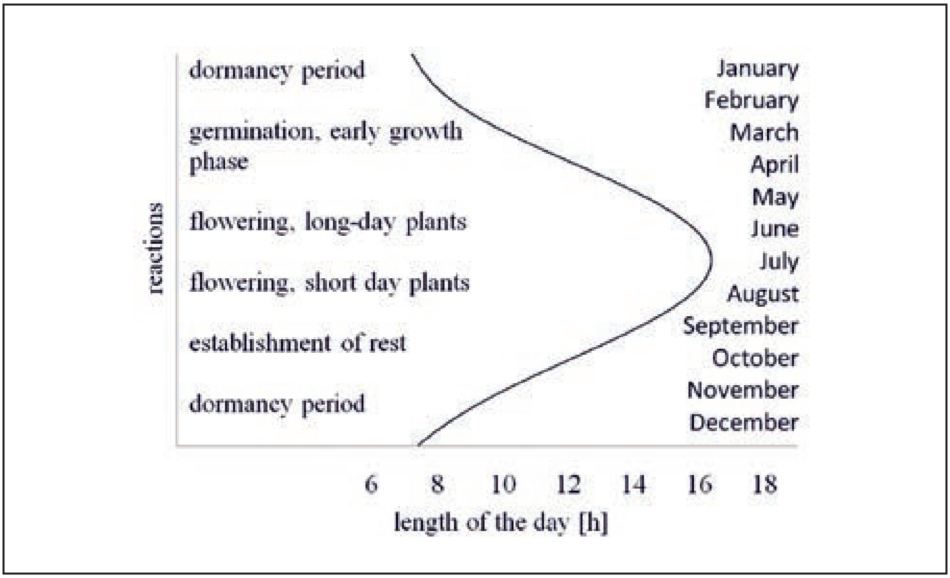


Fig. 2. Photoperiodic cycle plants in temperate climates

Basis of monitoring and controlling microclimate system for plants production

The uses of electric light sources provide plants for home appropriate amount of light. The obtained radiation energy is electromagnetic radiation having a wavelength in the range of 380 to 760 nm. Analyzing the electric light source we have to choose incandescent lighting (bulbs, arc lights), luminescent lighting (e.g. fluorescent lamps), mixed and electroluminescent (LEDs). Analysis of the results of numerous scientific papers and research conducted in recent years shows that the most important radiation relevant for the process of photosynthesis and photomorhogenesis in plants is light of a length of 662 nm (close to red colour), supported by light of a length of 453 nm (close to blue colour) (Puternicki, Lisak, Treder et al. 2012; Klamkowski, Treder et al. 2012; Żupnik, Grzesiak et al. 2012; Tamulaitis 2005).

In the light spectral distribution of high pressure sodium lamps follows that majority of the radiation is emitted in range of 550 to 640 nm, and therefore in the range of negligible absorption of chlorophyll "a" and "b". From the spectral characteristics of metal halide lamps, we see that, as in the previous case, most of the light radiation is emitted in the same range, which is less favourable for the plant. Analyzing the spectral characteristics of selected LED provides the conclusion that the wavelength emitted by the selected LED represent the most favourable spectrum for plants in LEDs of colours: photo red (660 nm) and royal blue (455 nm) (www.cree.com).

Luminous efficiency and durability are the elements that are taken into account when choosing electric light source. A comparison of different types of lighting, in terms of their efficiency and durability shows that the most favourable characteristics show a semiconductor light source, which are the most effective and viable light sources, which demonstrates luminous efficiency at the level of 60–303 lm/W and durability at the level of 50 000 hours.

A LED panel was created for growing plants. The designed panel is adapted for growing plants in the artificially created microclimate conditions. It consists of aluminum flat bars forming a rectangular panel on which LEDs are mounted. The system also functions as a heat sink, which draws the heat away from the semiconductor. The LEDs are arranged so as to ensure maximum uniform mixing of colours of light across the whole of the illuminated area. On three parts of aluminium flat bars, a serial connection is made with 4 LEDs emitting light of a blue colour (455 nm) and 11 LED emitting red light (660 nm). Blue and red LEDs are powered from a single power supply. The panel is capable of adjusting the distance between the source of

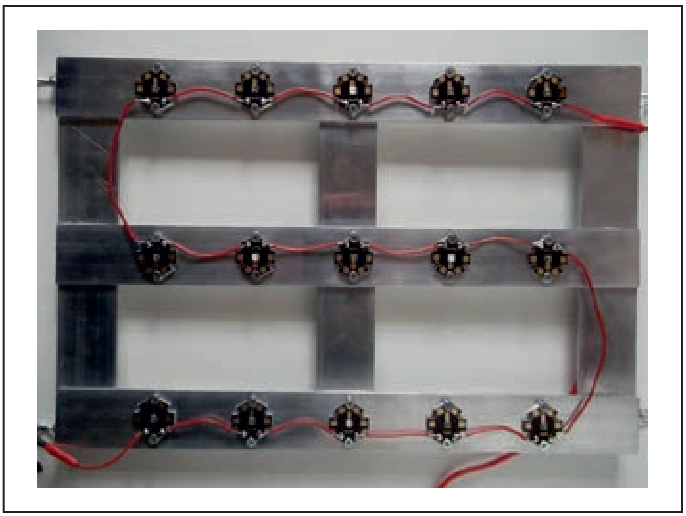


Fig. 3. The LED panel designed for growing plants

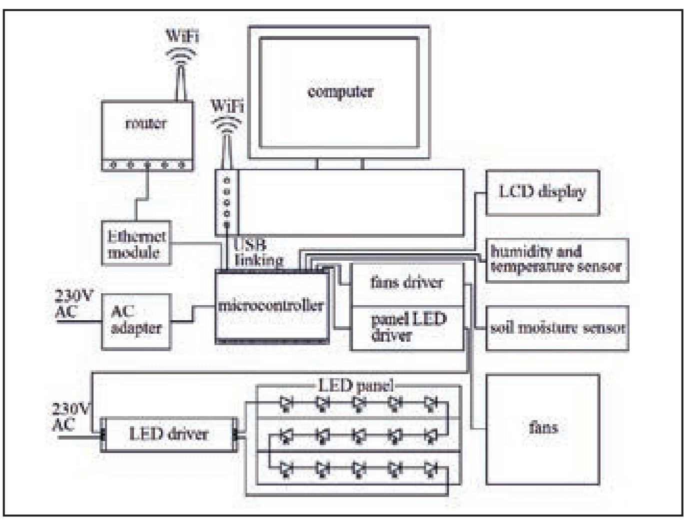


Fig. 4. Block diagram of monitoring and controlling microclimate

light and the plants (Fig. 3). Subsequently, we were provided with a unit responsible for reading, viewing and controlling environmental parameters.

The AVR microcontroller was used for the reason that it is a member of a family of systems with a very wide range of programming possibilities, and because of the construction, speed of operation and a broad range of helpful tools (Banzi 2011; Monk 2014).

In the project, we used an Arduino microcontroller combined with several sensors. The Arduino Leonardo is the module based on a microcontroller Atmega32u4. It has 20 input/output pins, it is equipped with a quartz resonator of 16 MHz, ICSP connector, microUSB socket and power and reset button. This microcontroller can control complex, multiple systems due to its multifunctionality. The most convenient way to run this microcontroller is to connect the system via a microUSB cable to the computer, because the processor on which it is based has a built-in USB communication, so the Arduino Leonardo can be connected to the computer as a virtual COM serial port (Oxer, Blemings 2009).The microcontroller controls parameters using the created software and controlled parts: LED and fans. The computer shown in the block diagram is only used to modify the program settings for the microcontroller (Fig. 4).

The system allows you to control plants photoperiodic cycle through the ability to set an appropriate duration of illumination during the daytime. Implemented software allows you to schedule hours of switching on and off the LED panel. Thanks to such a solution it is possible to cultivate plant species of different demand for light energy. In addition to lighting management, the system also has a program of stabilizing the temperature inside the room for growing plants. This is done by means of

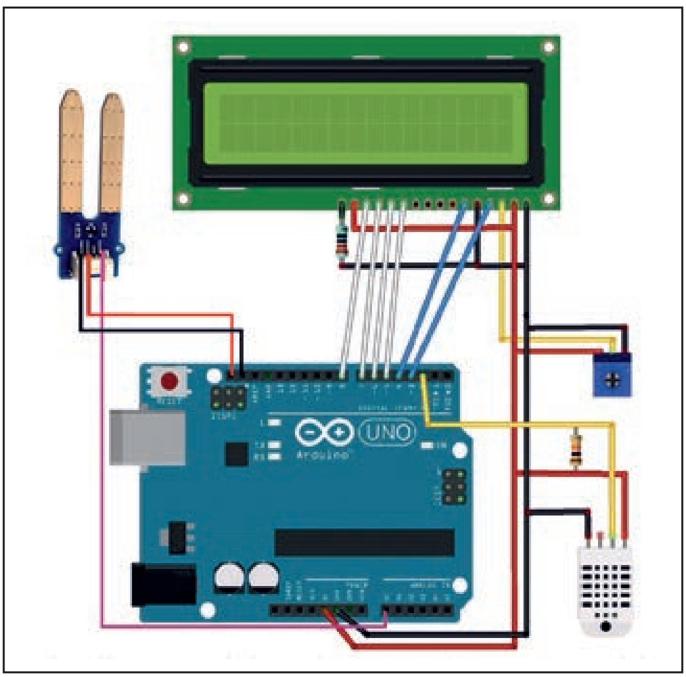


Fig. 5. The diagram of the microcontroller system with DHT22 sensor, soil moisture sensor and LCD display

Fig. 6. System with switched off and switched on illumination

two fans provided in the middle of the casing and a DHT22 sensor monitoring temperature and humidity (Fig. 5). The sensor providing the value of the temperature to the microcontroller causes the acceleration of the fan at a too high temperature or slowing down when the temperature is too low. The temperature value, expressed in degrees Celsius and humidity, expressed as a percentage, are displayed on the LCD. The sensor sends data every two seconds so that the system is under continuous control. This enables e.g. to react quickly in case of sudden changes in temperature. The system also allows for controlling water content in soil. The sensor, which is connected to the system, transmits data to the microcontroller.

The prepared program prompts a user with the pieces of information about the state of hydration of the soil by the light signal, realized by means of four LEDs located in the housing, which represent four states of soil moisture.

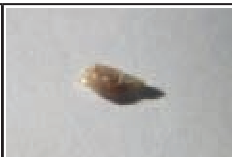
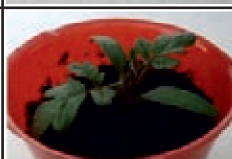
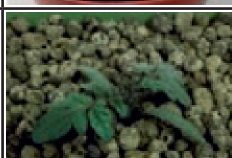
The microcontroller software is written in the Arduino IDE. Several libraries have been used in the project. The project uses the Ethernet library, which allows you to connect to the Internet via Ethernet module, LiquidCrystal library, which allows you to control the LCD display, DHT22, receiving the converted numerical value from temperature and humidity sensors.

Expander library allows you to increase the number of pins used by the Arduino (Monk 2014; Oxer, Blemings 2008).

The experimental data

To check whether the conditions produced within system climate are suitable for plant growth, a test was carried out. We planted two tomato seeds (Fig. 6). Both the seeds germinated at correct time. Within a week two pairs of leaves have grown from the seeds. The plants grow rapidly and look healthy. Dark green leaves and thick, correct stem, are evidence of adequate intensity of light radiation (Tab. 1). The premise of the study was to create and programming system of a microclimate control. Designed LED panel provides efficient source of light energy for plants with low power consumption. When combined with microcontroller electrical systems, they ensure stability and reliability of the system (Hudy, Noga 2014). Prepared program effectively controls the microclimate single parameter, which is confirmed by the carried out tests. The constructed and programmed model is able to create artificial conditions which fully meet the needs of the plants. The plants planted as an experiment showed a normal growth. It is a proof that all the processes run properly.

The steps of carrying out the experiment

Day 1		
Day 2		
Day 17		
Day 22		
Day 31		

There are very many opportunities of development for the project. The first is the domestic cultivation of vegetables and fruits. This solution enables cultivation of almost all demanding plants, regardless of the outdoor aura. The energy efficient light source used in the model makes this solution cost-effective, and therefore environmentally friendly (Gumula, Pytel, Piaskowska-Silarska 2014). This project can also be developed and used in crops on a large scale. The control system can adjust the parameters of the environment to the needs of crops. The adaptation of light whether moisture content to plants and appropriate cultivation process automation could improve and enhance the production of selected plant species.

Summary

Poland is located in the temperate climate zone characterized by a deficit of natural light during the early spring, late autumn and winter (Raclavská, Corsaro et al. 2015; Gumuła, Pytel, Piaskowska-Silarska 2014). Therefore, the use of artificial light sources or supplementary lighting for growing plants is a means of intensifying their cultivation, and enhances the quality of the crops. The cultivation in an artificially created environment depends on many factors that affect the normal growth of plants.

The suitably chosen light, temperature, air, soil, humidity and water are needed to create a microclimate. Lack of one of these factors can lead to stop of plant growth or to increase susceptibility to various diseases. To ensure the plant with appropriate atmosphere, we have to recreate the environment close to natural, conditions in which the plant is present in nature. The device with the embedded system was made. The model was designed to provide optimal environmental conditions for growing plants in artificial conditions. It consisted of the control section (the microcontroller) and controlled (the sensors) located inside the cultivation space. The system allowed controlling the plant photoperiodic cycle through the ability to set an appropriate duration of lighting per daytime. Implemented software allowed scheduling hours of switching on and off the LED panel. Thanks to this solution it was possible to crop plants of different light energy needs. In addition to lighting management system, the program has the ability of stabilizing the temperature and humidity inside the space of growing plants. The system also allowed for controlling the water content in the soil. The program displayed information about the state of hydration of the earth by the LED light signal. The data from the sensor were displayed on the LCD screen in numerical form, and Ethernet module connected to the microcontroller allowed to send and receive data from the network. Thanks to this solution we could control the microclimate conditions from anywhere.

The tests confirmed that the device was able to create artificial conditions that fully meet the needs of the plants.

During the experiment we planted crops, which showed healthy growth, and this is proof that the processes of photosynthesis and photomorhogenesis run properly.

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Abstract

The paper describes a practical application of an embedded system for controlling selected microclimate parameters. The microclimate control system was designed, performed and programmed. The study was preceded by an analysis of a possibility of growing plants in artificial climatic conditions. An effect of light energy on a plant growth and types of electric light sources were presented. The aificial light sources used in crops of useful plants under opaque shields were used: light source technologies were analyzed and compared in terms of an optimal lighting efficiency, durability and spectral composition of radiation. The control system is described: it consists of a control unit and controlled components. A software is designed for microcontroller, which controls individual elements of the system. A block diagram of the system was shown. In order to verify the correct functioning of the system, an experiment confirming a correct and progressive growth and development of the selected plants were performed.

Key words: embedded system, microclimate parameters control, protection of environment, environmentally friendly energy sources

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