Application of Light Sensors Amplifier and Wireless Networking Sensor for Ambient Light Data to the Android Platform

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Abstract: *Modern technologies of growing different plants types in greenhouses envisage automated systems use for monitoring climatic parameters, on which the ripening of fruits and yields depend. At the development and application of such automated systems, the focus is on measuring the accuracy of temperature and humidity soil, whereas to determine the level of illumination used sensors, that measure the total illumination or Photosynthetic Active Radiation (400-700 nm) with error up to 20%. Under conditions of insufficient photon flux density, even at the optimal moisture level and temperature in the greenhouse, fruiting and crop yields may not achieve high performance. This article proposes a greenhouse lighting control system in which the LI-200R Pyranometer and LI-190R-BL Quantum Sensor measure not only total illumination from the wavelength of 400–1000 nm, but also PPFD from a wavelength of 400–700 nm. Light Sensor Amplifier provides an increase in the source signal of the measuring sensors and reduces their measurement error to 1%. The applied SMART Connectivity Platform ESP8266 Version ESP 07 is more robust to interference and ensures the transfer of measured data to the server. Created software application for smartphones with Android OS, ensures remote user access to the database via the Internet for remote control and analysis of climatic indicators in the greenhouse. The proposed illumination control system in the greenhouse contributes to the improvement of precision farming.*

Index Terms: *Light Sensor Amplifier, Quantum Light Sensor, Internet of Things, Greenhouse.*

I. INTRODUCTION

Intensive development of industrial enterprises is accompanied by an increase of natural fuel resources use and the release of chemicals into the environment, which worsens the ecological condition and climatic conditions, reduces the development efficiency organisms. Compared to animals, plants have a soil attached lifestyle, therefore, they are more sensitive to abiotic factors effects, in particular, to the light influence. This is particularly evident in megacities, where, in conditions of insufficient precipitation, dust can cover the plants leaves with a dense layer and reduce the photons amount, entering the chlorophyll. The photon flux density amount is one of the most important for plant development. It is known, that higher plants produce about 0,6-0,65 g of dry matter for each mole of the photons amount. The total illumination rate during the year varies from 2,5 to 25 $mol \cdot m^2 \cdot day$, depending on the climatic zone. At the longed exposure of low values total amount photons, which arrives at leaves, important life processes in plants can be suppressed.

Many countries, which located in the temperate climate zone, greenhouses are increasingly being used for creating optimal growing conditions for plants, where climatic conditions indicators for plant development are monitored by computerized means whit using wireless sensor networks (WSNs). Through these networks, farmers of the greenhouse can obtain information whit Internet stations monitoring about temperature air and soil humidity, light intensity and remotely adjust these value in greenhouses.

Scientific publications earlier have it was reported on the success and prospects of using WSNs not only for monitoring plant growing conditions in the fields [1] but also on the vegetable greenhouse [2]. At the same time, actual problems of monitoring and remote control the Photosynthetic Photon Flux Density (PPFD) in greenhouse remain insufficiently disclosed. This reading is important for plant development since the carbohydrate synthesis amount depends on the number of photons entering the leaves per second per 1 m^2 in the 400-700 nm wavelength range [3].

In modern greenhouses' management systems, WSNs can calculate PPFD based on Photosynthetic Active Radiation (PAR) or Photosynthetic Photon Flux (PPF) data, obtained from Internet servers and measurement sensors installed in the greenhouse.

The greenhouses are built from various materials, including glass, plastic film, and other similar transparent materials, which have a various refractivity and reflectivity index of the sun's rays, therefore photons density in natural light inside and outside the greenhouse is different. To reduce the error in calculating the PPFD index, it is necessary to continuously monitor and adjust the measured data taking into account cloudiness levels, dust pollution, and the refractive index of the sun's rays with these building materials. The photon flux density measured by the sensors at the traditional approach is calculated and maintained automatically by computer means located within the greenhouses. At the same time, remote correction of the specified data remains difficult and problematic.

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Recently, in greenhouses for the implementation of additional artificial lighting used LED lamps with different characteristics of the ability to generate light of a certain wavelength. It is known that light can influence plants differently, depending on the wavelength.

It was reported, for example, that light waves <380-430 nm long reduce the inter-nodular part of plants and increase their cold resistance. Light waves in the range of 600–780 nm promote rapid plant growth and carbohydrates intensive synthesis, and waves >780 nm can increase the plants' temperature, which may lead to their death [3].

Artificial lighting systems greenhouses are increasingly using lamps with colored LEDs of the XQ-E, XQ-A and XP-E series [3], which are capable of emitting light whit different wavelengths to provide optimal illumination and, consequently, better ripening fruits, of enhancing yields. At the using such lamps, arises is a need in continuous monitoring of the photon flux density and maintaining the illumination level with wavelengths that are optimal for specific plants types, grown in the greenhouse. The traditional method of monitoring the photon flux density envisage of periodic measurement, readings sending to the central computerized control unit and their visualization on displays, located in within the greenhouse. At the same time, the problems' measurement accuracy and remote control of the photon flux density with different wavelengths remain unresolved. To solve the above-mentioned problems and providing automation greenhouse lighting control, we proposed the using sensors of the increased measurement accuracy PPFD whit different wavelengths and also nRF24L01 Wireless Networking Sensor for wireless transmission of measured data to the server and later their visualization on smartphones whit OS Android.

A. Important Characteristics of Arduino Uno REV3

In this project, the Arduino Uno REV3 electronic board was used, which is an open platform. Various sensors can be connected to it to measure temperature, humidity, and other physical indicators. The board contains an ATmega328 microcontroller with a clock frequency of 16 MHz, which provides high-speed data processing. Through the USB cable, the electronic board can be connected to a computer and reprogram the microcontroller. Power supply voltage 7-12 V [4].

B. Important Characteristics of LI-190R-BL Quantum Sensor

The LI-COR Quantum sensor (fig.1) measure PAR and PPFD in range 400 to 700 nm with an enhanced silicon photodiode mounted under a cosine-corrected acrylic diffuser. A custom spectral filter helps achieve the desired spectral response. The sensor output is a current (µA) signal that is directly proportional to hemispherical PAR. A sensor show measurements number of photons, falling on m^2 per second $(\mu mol \cdot m^{-2} \cdot s^{-1})$ [5].

Fig.1 Quantum sensor LI-190R-BL with 3-wire bare leads cable

C. Important Characteristics of LI-200R Pyranometer

The LI-200R (fig.2) used for measures global solar radiation in the range 700-1000 nm (on a horizontal surface) with a silicon photodiode mounted under a cosine-corrected acrylic diffuser. The sensor output is a current (µA) signal that is directly proportional to hemispherical solar radiation. A sensor show measurements a number of photons into units of light radiation $(W \cdot m^{-2})$ [6].

Fig.2 Pyranometer sensor LI-200R with 3-wire bare leads cable

D. Important Characteristics of 2420 Light Sensor Amplifier

This sensor (fig.3) was used in the project to amplify and stabilize the electrical signal from the measuring sensors to the Arduino Uno REV3 platform.

The 2420 Amplifier provides generates an output signal up to 5,0 V and down to –2,5 V over the entire input supply voltage range (+3,8 to 28 VDC). The output signal is linearly provided by the light sensor with an offset of ± <10 µV, meaning that 0 µA of input current yields a 0 V ± <10 µV output voltage [5].

Fig.3 Appearance of 2420 Light Sensor Amplifier

E. Important Characteristics of SMART Connectivity Platform ESP8266 Version ESP 07

The Espressif Smart Connectivity Platform (fig.4) was used in our project to provide high-speed data transfer from lighting sensors to the server and smartphones (with OS Android) over a wireless Wi-Fi network.

This module Version ESP 07, in comparison with other earlier versions, has an advantages number, it aligns the original cascades and antennas, which significantly increases the sensitivity and signal transmission radius. The supply voltage is 3,3V, the operating frequency is 2,4 GHz, the radiation power is 24dbm, the serial port speed is 115200 bauds by default, applied are 802.11 b/ g / n wireless protocol, ceramic antenna, there is connector external antenna [7].

Fig.4 Appearance of SMART Connectivity Platform ESP8266 Version ESP 07

F. Objective

The objective of this project was concluded to create an automated system of control the photon flux density whit a wavelength of 400 to 1000 nm for used in the greenhouse.

Realize a wireless transmission for the measured data to the server and smartphones (with OS Android) for remote PAR level control and ensuring optimal lighting conditions to increase various types yields of plants grown in the greenhouse.

This product can be used in greenhouses where there is a need to realize remote control of PAR lighting.

G. Future Aspects

- Apply sensors the Light Sensor Amplifier to improve the accuracy of PAR, PPFD measurements and determine the optimal lighting parameters for each type of plant grown in the greenhouse;
- Implement a wireless network module less susceptible to interference for ensuring high-quality data transfer a remote server;
- Create software for control PAR and PPFD lighting with support multiple languages on the Android platform;
- Improve the security of access to measured data on the Android platform.

II. STATE OF THE ART

The systems managing of climatic conditions in greenhouses is constantly being improved. Most of these systems are aimed at maintaining optimal values of temperature, humidity air, and soil.

In the existing monitoring systems, the level of illumination, created on the Arduino platform, photon flux density measurement sensors with a wavelength of up to 700 nm are used, which are not capable of measuring photon fluxes with a higher long wavelength. Besides, to reduce the measurement error, the sensors often need to be calibrated, which complicates their use. In the monitoring system, SMART Connectivity Platform ESP8266 module is traditionally used to transfer measured data over wireless networks. Its early versions are sensitive to the influence of various wave interferences that may occur in the greenhouse and beyond, therefore, during transmission, data may be partially lost, not recorded on the server and not visualized on smartphones with the Android operating system.

In this project, Quantum sensor LI-190R-BL and Pyranometer sensor LI-200R are used to measure the photon flux density which the range is 400-700 nm and 400-1000 nm, respectively. This allows to greater photon flux control photon fluxes of higher wavelength and more precisely to manage plants farmed in the greenhouse. Each sensor is connected to the Arduino UNO REV3 platform via the 2420 Light Sensor Amplifier, which not only amplifies and stabilizes the electrical signal from the measuring sensor in the circuit but also improves the measurement accuracy, eliminating the need of frequent measuring sensor calibration.

To ensure data transmission over the wireless network from the Arduino UNO REV3 platform to the server and smartphones (with the Android operating system), the project used the SMART Connectivity Platform ESP8266 Version ESP 07 module, which is more resistant to various wave interference and transmits a stable signal to a greater distance, compared with similar modules earlier versions.

III. METHODOLOGY

The project used the Internet of Things (IOT) and the software application, created for smartphones (with OS Android). Envisaged interaction of the Quantum sensor LI-190R-BL for measuring the wavelength photon flux density of 400-700 nm and the Pyranometer sensor LI-200R for measuring the photon flux density of long-wavelength to 1000 nm, 2420 Light Sensor Amplifier for amplifying and stabilizing the original electrical measuring sensors signal, also SMART Connectivity Platform ESP8266 Version ESP 07 for transmitting wirelessly the measured indicators to the server and smartphone with Android OS (fig.5).
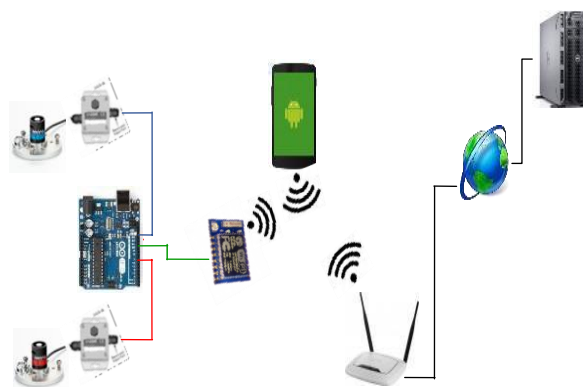

Fig.5 General scheme of the photon flux density control in the greenhouse

At the core of the methodology, it was proposed to carry out a more accurate the photon flux density measurement in the greenhouse and transfer this data over the wireless network for the server to analyze and display the results remotely on the Android smartphone application. Processed data on the server can be used to determine the density of the additional photon flux necessary for the effective development of different plants types, grown in the greenhouse.

Data transmission from the measuring sensors to the server is carried out over the wireless network by the SMART Connectivity Platform module ESP8266 Version ESP 07, in which you can independently program the SSID and access point password. After the module is connected to the Internet, its key is authenticated on the server to gain access to the database. Such authentication is carried out when connecting to the server via the Internet Android applications from smartphones. With the help of the proposed Android application, it is possible to sample and analyze the indicators of the photon flux density in a greenhouse for the interested period time.

IV. LITERATURE SURVEY

The integration of wireless sensor networks (WSNs) in agriculture is a recent concept, which has leads to what is called precision agriculture. The agricultural WSNs monitoring of the air temperature, air humidity, soil temperature, soil moisture, leaf wetness,

atmospheric pressure, solar radiation, wind direction, amount rainfall and etc. [8].

Countries, which located to the temperate climate zone, when growing light-loving plants, there arises the low levels' problem of natural illumination, or rather a low photon flux density, in which fruits do not ripen. To solve this problem, light-loving plant species are increasingly grown in greenhouses, where lighting can be controlled automatically by sensors.

At the creating automated monitoring system of the lighting level in the greenhouse, the main attention is paid to the sensors using, whit capable of controlling the total illumination, measured in lux and photosynthetic active radiation from a long wavelength of 400-700 nm.

In the automated system control climate greenhouse by Li Juanjuan, it is proposed to use the light intensity sensor model NA2D10, but it can measure only the intensity of visible spectrum illumination from 380 to 780 nm in the range of 0-200 klux with accuracy ±3% [9]. Adjustment of the gain and signal multiplying in this sensor are not provided, which greatly complicates the calibration, which is recommended to realize every 2 years.

Intensity illumination control is also provided in the portable, built-in computerized greenhouse management system for growing cherry tomatoes developed by N. Thirer and I. Uchansky. The system consists of two low-cost Altera development boards: the DE0 Nano (as an operator unit) and the Cyclone V GX Starter Kit, which serves as a data acquisition unit. Light intensity sensor (G1118) is connected to this unit – with output current (for a 100 Ω load) between 10-3A to 10-14A for a 10-2 w to 10-13 w radiation. This sensor capable is measuring illumination whit long wave only 400-700 nm. The measured controlling reading to store on the SD card and are used to control the motors blinds [10], which regulate the illumination in the greenhouse. It should be noted that SD cards are as unreliable data storage devices because after a long time of work or as a result of electromagnetic radiation, they may be damaged and the recorded information will not be available. We believe that using a remote server as a repository of information can ensure the preservation and security of access to information.

The computerized controlling model of greenhouse climate indicators proposed by S. Yang and D. Simbeye provides for the use of a computer and the LabWindows / CVI program for monitoring not only air temperature, relative humidity, and carbon dioxide level, but also lighting intensity. Low-level input signals received from the light sensor are processed, amplified and then transmitted to the computer system through a data acquisition unit (DAQ). Then the computer is comparison there with the standard parameters and provides control signals to the illumination intensity adjustment relay. Light intensity is measured by a light sensor in the range from 0 to 100 Klux (KRIWAN Industrie-Electronik GmbH), which can be calibrated, taking into account possible significant temperature fluctuations in the greenhouse during the day and at night. The sensor electrodes are not polarized, the input preamplifier impedance is high ($>Ω1010$) with low-temperature drift [11]. We believe, the lack of data transfer tools wireless for Android mobile devices in the proposed system limits its use for remote monitoring.

The monitoring system the microclimate in the greenhouse, proposed by G. Ipate with coauthors, envisage of the measurement illumination level whit the use BH1750FVI sensor for the I2C bus interface. This chip contains an integrated analog-to-digital converter (ADC), which integrates the currents from the photodiode to receive digital 16-bit data. This sensor is capable of measuring a wide range at high resolution (1-65535 lux) and the peak wavelength of 560 nm [12]. In order to enhance the ability to control the illumination intensity, in this monitoring system also proposes to use the VEML6070 UV sensor, manufactured by Vishay Semiconductors using CMOS technology and having an I2C protocol interface. The linear sensitivity of the VEML6070 sensor to solar ultraviolet radiation is adjusted by selecting a suitable external resistor [12].

The project by Hussain and coauthors [13], aimed at improving the efficiency of monitoring climate parameters in greenhouses, proposes to use an XBee-based wireless sensor network, which automates the measurement of temperature, humidity, and light intensity. In this system, a standalone XBee module, i.e. without a microcontroller, integrated with certain small-sized sensors. All measured parameters are transmitted wirelessly to a computer for analyzing and initiating the corresponding commands to specific devices in order to overcome the lighting reading drifts of the greenhouse.

V. FUTURE PROSPECTS AND CONTINUED WORK

The project aims to create a monitoring system for lighting in the greenhouse, which provides control of the photon flux density of a given wavelength the range of 300-1000 nm and makes it possible to determine the optimal illumination level needed for different plants types grown.

The use in the proposed system not only of the PAR measurement sensor but also of the Pyranometer makes it possible to control the photon flux density whit longed wave above 700 nm, which is important to prevent overheating of the plants leaves and lower yields.

It is known that NA2D10 light intensity sensors and other similar measuring lighting sensors, which are used on Arduino platforms, can increase the measurement error every 2-3 years by about 2-5%. In this regard, there is a need for their periodic calibration, which is difficult to realize. In our proposed project, the 2420 Light Sensor Amplifiers are used, which provide 15 discrete settings for amplifying the electrical signal depending on changes in lighting intensity and voltage ranges, which increases the accuracy of indicators measurement and increases the sensors' lifetime without calibration.

The use 2420 Light Sensor Amplifiers is perspectives, as they are compatible with various measurement sensors that operate on the Arduino platform, therefore they can be applied and in future other similar projects.

VI. SOCIAL RELEVANCE AND EFFECTIVENES

In modern conditions of intensive increase in population, the food supply problem is becoming one of the most pressing. In countries where natural climatic conditions are not optimal, in agriculture for growing important cultivated plant species, greenhouses are increasingly used.

Most of the previously proposed projects, the main attention was to direct on specifics the creating monitoring systems with the ability to control temperature, air, and soil humidity, as well as general or PAR lighting in a greenhouse. It is important to note that with optimal temperature and humidity indicators, the insufficient measuring accuracy photons flux density from different wavelengths can lead to poor plant growth, a significant decrease of yield or increased flows energetic resources for growing plants.

The monitoring system proposed by us will provide more accurate control of the photon flux density in the greenhouse and help optimize the conditions for plant growth and fruiting. Created software application for use on smartphones with the Arduino platform, allows farmers to remotely determine the need for additional lighting or limiting the flow of photons for a plants' particular type, that is grown in the greenhouse.

The measured light readings are stored in a database on the server, so if necessary, the farmer can open the data to scientific laboratories for help and scientifically-based recommendations for correcting the level of illumination, that is optimal for growing specific plants types. The planned in the future to create a multilingual application compatible with the OS Android, which will make it possible to combine the databases of several greenhouses into a single international specialized network, in order to more effectively solve current agricultural problems. Providing access to data via the Internet will facilitate international cooperation not only of farmers but also of scientific researchers, whose efforts are aimed at solving the problems of improving the growing plants' technology in greenhouses.

VII. RESULT ANALYSIS

In proposed monitoring system of illumination level, created on the Arduino Uno REV3 platform, used of the 2420 Light Sensor Amplifiers increased the output level of the Quantum sensor LI-190R-BL and Pyranometer sensor LI-200R, which ensured a reduction measurement error of the values PPFD and PAR. This is indicated by the results of an experiment in which PPFD values were measured whit Quantum sensor LI-190R-BL with and without the use of 2420 Light Sensor Amplifiers. As analyzing a result, the experimental data shown in table I, it is revealed that the measurement error of the Quantum sensor LI-190R-BL without using the 2420 Light Sensor Amplifiers is on average 4,2%, whereas for the control calibration sensor the measurement error is on average 0,2%.

Table I. Average PPFD in the greenhouse during the summer vegetation period of 2018 in the Kiev region of Ukraine

Measurement options	Photosynthetic Photon Flux Density, ($\mu mol \cdot m^{-2} \cdot s^{-1}$)			
	May	June	July	August
Control calibration sensor	73,4± 0,13	79,1± 0,16	99,8± 0,21	177,3± 0,46
Quantum sensor LI-190R-BL	77,3± 3,24	83,7± 3,43	105,9± 4,13	184,2± 5,15
LI-190R-BL whit 2420 Light sensor amplifier	74,3± 0,37	80,2± 0,48	101,2± 0,64	179,7± 0,89

At the using the 2420 Light Sensor Amplifiers in the lighting control systems, the measurement error of the Quantum sensor LI-190R-BL decreased on average to 0,6%, which helps to more accurately predict the change tendencies of the greenhouse's lighting changes.

The use of the SMART Connectivity Platform ESP8266 Version ESP 07 has improved the resiliency of data transmission over a wireless network, compared to similar sensors from earlier versions that have been offered in other previously published projects.

The possibility of reprogramming sensors on the Arduino Uno REV3 platform, to ensure the necessary mode of their synchronization and collaboration, is provided.

In the created application for smartphones with OS Android, measured values introduction to the server is carried out not only automatically, but also manually. Users are given the opportunity to create requests to the server to receive reports with indicators of greenhouse lighting for the interesting past period time. The created database already stores information on the optimal lighting conditions for 72% of plant species grown in greenhouses located in temperate climatic zones.

VIII. CONCLUSION

This project was developed on the basis of IOT and computerized software applications that are available for free use. It can be useful for researchers and farmers in different countries, where Arduino tools are used to improve the greenhouse lighting control system and increase yields.

A proposed lighting control system operates on the Arduino Uno REV3 platform, based on the low-power, high-speed 8-bit ATmega328P microcontroller with high bandwidth up to 20 MIPS at 20 MHz. Provides the ability to connect to the Arduino platform and other sensors, as well as of the integration of this Arduino platform with sensors into other similar platforms and projects.

Illumination sensor and a Pyranometer use, which are not synchronized with each other from the clock frequency of the analog-digital conversion, contributed to increasing their resistance to the electromagnet waves influence and the calculating accuracy the photon flux density of long-wavelength ranges of 400-1000 nm.

Applied 2420 Light Sensor Amplifiers provide a significant reduction in the measurement error of the sensors and facilitate their calibration. A using perspective of the 2420 Light Sensor Amplifiers with other types of measuring sensors to amplify the original signal is also noteworthy. The composite modules' interaction of the illumination control system in the greenhouse whit the users is carried out according to the algorithm indicated schematically in fig. 6.

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The created software application uses a wireless network for data transmission at the Internet, provides visualization of Photosynthetic Active Radiation and Photosynthetic Photon Flux Density value on smartphones with the Android OS.

This allows farmers to view the indicators stored on the server, not only within the greenhouse but also to make decisions regarding the correction of the lighting level of several greenhouses, being at a considerable distance beyond their limits. Improving the accuracy of lighting control in the greenhouse contributes to the creation of more optimal conditions for the photosynthetic apparatus functioning of cultivated plants and the improvement of precision farming.
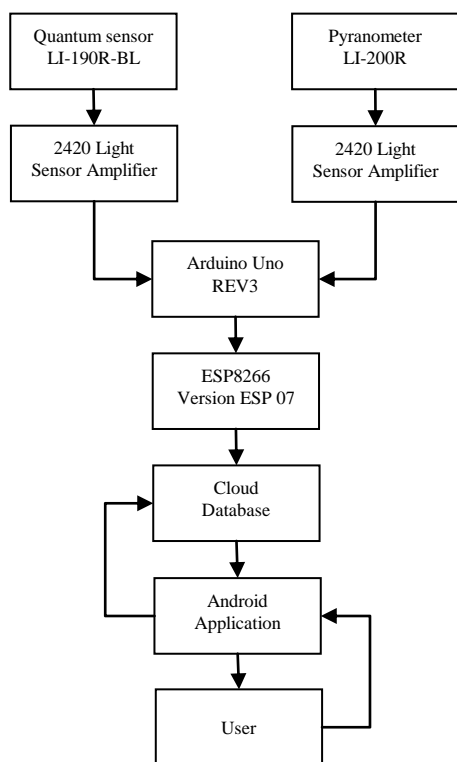
Fig.6 Algorithm Interaction between the components of the lighting control system and the user

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