Artificial Lighting Experimental Environment in Agriculture for Seed Germination

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***Abstract*—This paper explains the basic biology behind the idea of using artificial lighting for acceleration of a plant's development. The article deals with the control of power light-emitting diodes, the optimization and diagnostic possibilities of the spectrum are part of the presented experimental environment. Eventually conclusions were drawn about the feasibility and requirements of such a system to make it possible to implement.**

Keywords— photoreceptors in plants, greenhouse lighting, chlorophyll a, chlorophyll b, artificial seed germination, grow LED driver, light spectrum control

I. Introduction

Numerous solutions exist to enhance the yield of soil, ranging from chemical compounds to systems with full environmental regulation. Many of these solutions use some form of complementary or complete illumination, usually using LED technology.

The experimental environment is based on modular subsystems, due to easier modifiability [1-5]. The optimization of architectural structure is considered according to the following papers [6-8]. Real time data monitoring and logging is also a significant part of the research [9-12]. One of the effective ways of controlling the operation is closed-loops and compensation of disturbance [13-15].

II. Biological Background

A previous study has shown that chlorophyll a, chlorophyll b, cry2 and Phytochromes play a significant role in the development of plants. [16]

A. *Clorophyll a and clorophyll b*

Plants absorb the light spectrum in a similar but broader range as the human eye, but unlike humans, they absorb best red and blue light. Chlorophyll is one of the main molecules that enable plants to absorb and use the energy of light thus making photosynthesis work. In the higher plants, two main types of chlorophyll can be found with slightly different absorption curves. The small difference in the absorption characteristics allows them to capture different wavelengths, catching more of the sunlight spectrum. All oxygenic, photosynthetic organisms use chlorophyll a, but are differentiated by additional pigments such as chlorophyll b. Chlorophyll a absorbs light at wavelengths of purple, blue and red range of the spectrum, but reflects the majority of light in the green range. Additional photosynthetic pigments expand the spectrum of absorbed light, increase the range of wavelengths used in photosynthesis. The addition of chlorophyll b a to chlorophyll a expands the absorption spectrum as shown on Fig. 1.

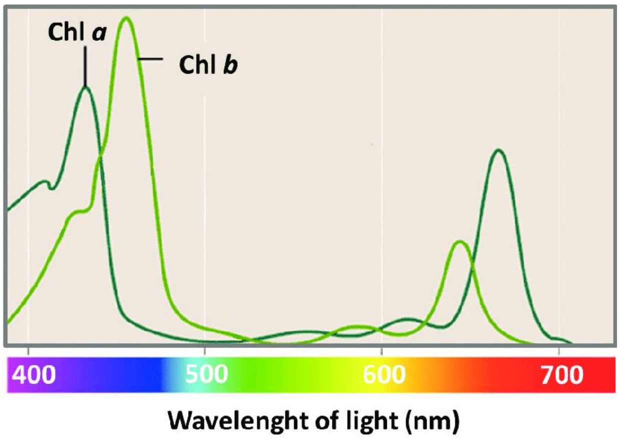

Figure 1. Absorption spectrum of chlorophyll a and chlorophyll b [17]

B. *CRY2*

Cryptochromes are a class of flavoproteins found in animals and plants. They capture light-related external stimuli and control the internal clock of plants. They are also associated with morphological reactions such as inhibition of stem elongation, dilation of the cotyledon, anthocyanin production, and photoperiodic flowering. Cryptochromes absorb UVA (ultraviolet), blue and green wavelengths. In plants, cryptochromes mediate phototropism in response to blue light. This response is now known to have its own set of photoreceptors, the phototropins.

Cry2 is responsible for the leaf and cotyledon expansion mediated by blue light. In transgenic plants, excessive expression of Cry2 increases the expansion of cotyledons stimulated by blue light, resulting in numerous broad leaves and no flowers instead of primary leaves and flowers. Cry2 genes have been shown [17] to delay flowering in continuous light and accelerate it in long and short days, indicating that CRY2 may play a role in accelerating flowering time in continuous light.

C. Phytochromes

Phytochromes are responsible for induction of flowering and seed development, they regulate stem and leaf elongation, seed germination, chlorophyll synthesis, seedling elongation, size, shape, number and movement of leaves, timing of flowering in adult plants and "shade avoidance syndrome." Phytochrome-regulated responses are mediated by the ratio of red and far-red light, which affects the photostationary state of the phytochrome molecule. They can be classified as either type I, which are activated by far-red light, or type II activated by red light. Phytochromes also sense light, which causes the plant to grow towards it (phototropism). The above is illustrated in Fig. 2.

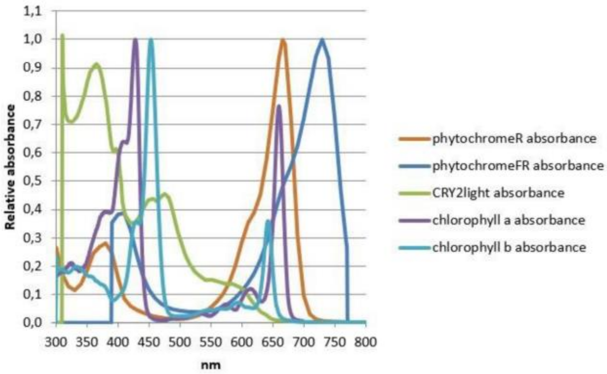

Figure 2. Relative absorbance of different photoreceptors in plants [16]

III. Expectations from a System

The main goal of an artificial lighting system is to provide the plants with light that has an optimal spectral distribution, while adopting to the circadian cycle of the plant. To achieve this, such a system needs to be able to keep track of the time of day and control the lighting of the environment accordingly.

The energy-efficiency of such a system can be greatly improved if the sun’s own radiation is used and the artificial lights only provide supplementary illumination at the peak wavelengths of the absorption spectrum. This way only red and blue lights need to be used to achieve notable results as the rest of the spectrum is covered by the natural light. When using this technique, a system could easily adopt to a plant’s natural circadian cycle just by monitoring the natural light, therefore it could be used in geographic areas of widely varying sunny hours.

IV. Light Source

A. Incandescent light

Incandescent light bulbs have a small initial cost compared to the cost of energy it is using over its lifetime. [20] They typically have a lifetime of around 1000 hours. [21]

The luminous efficiecy of a typical 120V incandescent light bulb is 16 lm/W, compared to the 60 lm/W for compact fluorescent lights and 150 lm/W of some LED sources [22].

B. Fluorescent lamps

While fluorescent lamp fixtures have a higher initial cost, compared to incandescent bulbs, because of the required external circuitry, it has lower energy consumption, which offsets for the initial costs. [23]

C. LEDs

Peak efficiency can be reached by using Light Emitting Diodes (LEDs) as they can emit light in a narrow band of the spectrum, as opposed to more traditional methods of lighting such as incandescent light bulbs or fluorescent lamps. LEDs also generally have directional radiation characteristics compared to the other mentioned light sources. These characteristics make LEDs a perfect candidate for this application as the relevant molecules’ absorption curves have their peaks close to each other, therefore 2 well-chosen LED types can cover the most sensitive parts of the absorption spectrum. [24]

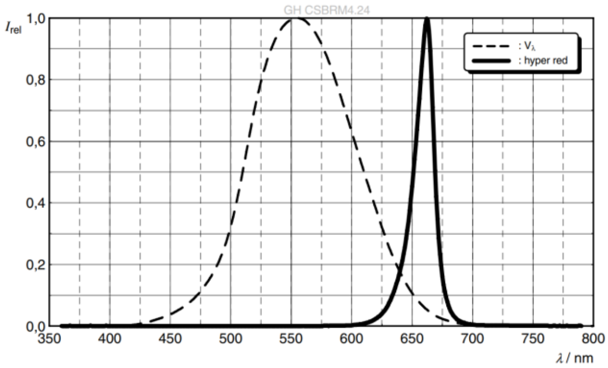

Figure 3. Relative Spectral Emission of OSRAM GH CSBRM4.24 LED [18]

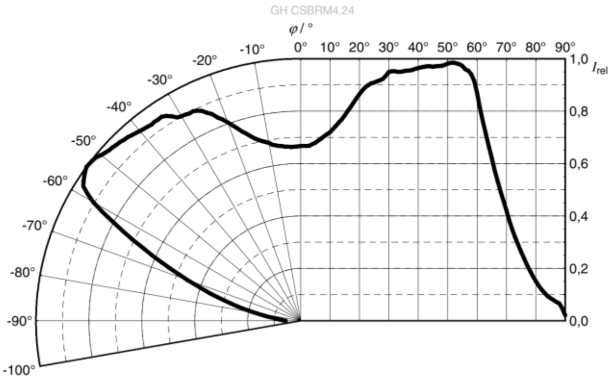

Figure 4. Radiation Characteristics of OSRAM GH CSBRM4.24 LED [18]

The LEDs’ characteristics also allow it to be easily dimmed by using PWM controls or constant current sources (Fig. 5). [25] As different plants may require different ratios of the supplementary red and blue light for optimal development, this enables for more universal solutions. [26]

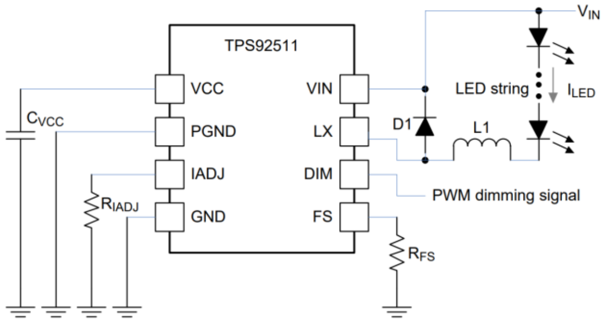

Figure 5. Example circuit for TPS92511 constant current LED driver IC [19]

D. *Solution used for the experiment*

For the experiment, 10w LEDs were chosen, together with a custom-made, LM3405 based constant-current driver circuit to provide them with a maximum of 900 mA (Fig. 6). The 10W IR COB LED needs more than 2A driving current, an individual current source circuit is added for the experimental setup for this purpose.

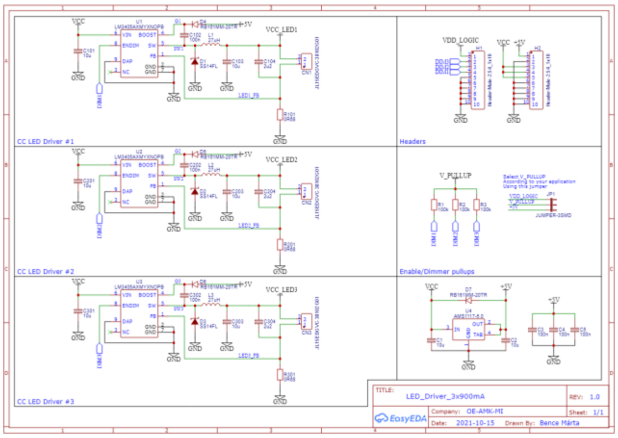

Figure 6. Schematic of the LED driver board

For practical reasons, the boards were designed in a way that they can be stacked on top of each other. The power and dimming signals can be fed to the PCBs through a base board, see on Fig. 7.

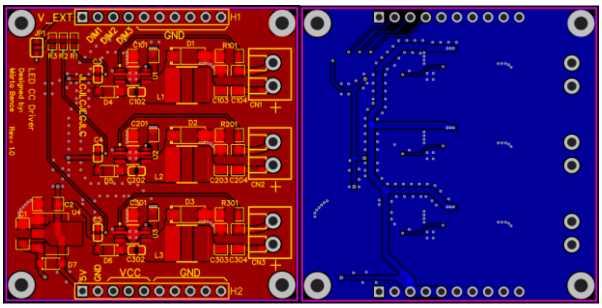

Figure 7. Top (left) and bottom (right) copper layer of the LED driver board

V. DESIGN OF THE EXPERIMENTAL ENVIRONMENT

The environment was designed to provide the plants with different wavelengths of light from above in a controllable manner (see Fig. 8).
The test equipment consists of several hardware elements:

- Tray for the plants
- 10W LEDs with cooling
  - 4x red
  - 2x blue
  - 2x warm white
  - 1x infrared
- Constant current LED drivers
- Arduino UNO
- Raspberry Pi 3 with camera

Figure 8. Picture of the test setup

The Raspberry Pi is used to set the brightness of the LEDs and also take a photo of the plants every hour with a camera module (Fig. 9).
The Arduino UNO is used to generate the PWM dimming signals for the LED driver circuits.
The software running on the Raspberry Pi is created with the help of Node-RED (Fig. 10). The flow consists of only 4 nodes, excluding the UI elements.
The Arduino UNO's task is simply to interpret a packet of bytes sent by the Raspberry Pi and set its PWM outputs' duty cycles accordingly.

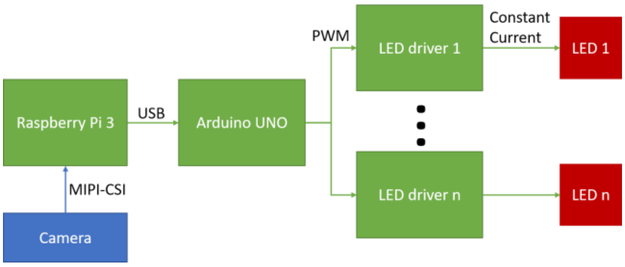

Figure 9. Block diagram of the hardware

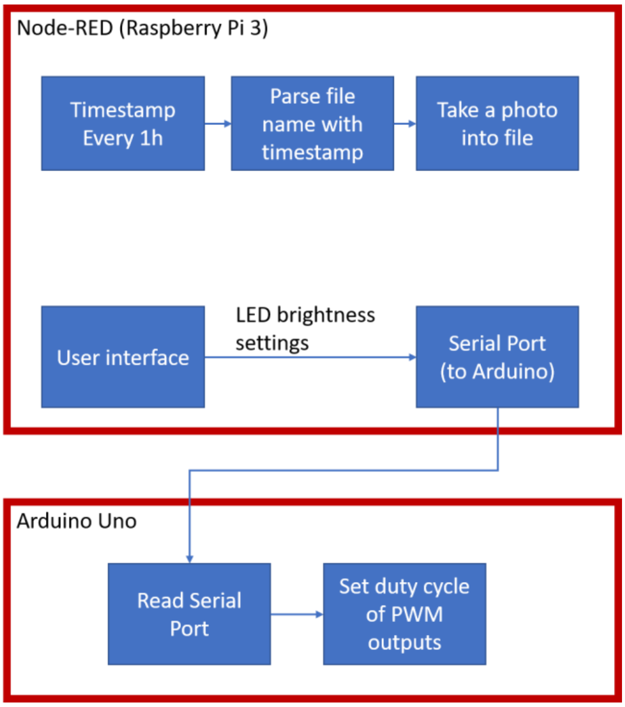

Figure 10. Block diagram of the software

VI. Conclusion

This paper aimed to show an optimized experimental indoor plant production environment. The design contains power LEDs and LED drivers, a light spectrum control system and a data logging application. The shown modular design can also be used for other indoor plant production applications. The proposed architecture is easily scalable, user-friendly, and robust. The article describes the relationship between the system components and includes an algorithm that demonstrates the control and measuring options.

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