Design and Implementation of Artificial Grow Light for Germination and Vegetative Growth

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Abstract. The purpose of this research is to build artificial grow light using LED for growing leafy vegetables from germination to harvesting (vegetative growth). Plants need to capture photons as energy for photosynthesis in 400nm – 780nm spectrum. Different plant species will respond differently to specific light spectrum. Many studies have been done to find optimal light spectrum for plant growth, but there are still many researches to be done because there are still many combinations of light and plants species to be discovered. Specific light spectra combination is called light recipe. This research will help botanist to discover new light recipe for plant species by mixing 6 light spectra with individual intensity and time control. The developed grow light system has graphical user interface that run in Android tablet, and uses MQTT protocol for communication between android application and grow light system. Light recipe and setting are stored in database and the system also has light sensor to monitor light environmental conditions. Grow light consists of 6 types of 3W high power LED with specific color spectrum: Royal Blue, Deep Red, Ultraviolet, Full Spectrum, Far Red, and Natural White. Testing result shows that the system can produce uniform light distribution across the 50 x 50 cm grow area on average 22.6 µmol m-2s-1 using 60° lens. Germination result of lettuce using grow light shows good results compared to sunlight.

Keywords: Artificial grow light, LED, PAR, MQTT

1. Introduction
Plants require air, water, nutrients and light to grow. Light is absorbed and reflected at plant leaf surface and then converted to chemical energy as carbohydrates for plants, and some of them are converted into heat. In urban agriculture, sunlight can be replaced by artificial grow light [1]. Light-emitting diode (LED) can mimic natural light to ensure plant growth and development of photosynthesis, where changes in light intensity and wavelength can manipulate the plant metabolism [2]. Studies have shown the effects of blue and green light on seven plant species: tomatoes, cucumbers, pepper, radishes, soybeans, lettuce, and wheat, where it was concluded that green light has less significant impact on the seven plants while blue light has more significant impact on those plants, while radish plants, soybeans, lettuce and wheat had less significant impact from blue light [3].
Artificial LED lighting, compared to conventional fluorescent light, can enhance growth characteristics and increase total phenolic content of lettuce leaf [4]. Seed germination of Arabidopsis thaliana, for both mutant and wild type, is faster in red light compared to another wavelength [5]. The phenotypic response to red, far-red and R:FR can vary among species, but also with growing conditions, current knowledge about plants response to light is being applied in horticulture to improve crop yield and quality [6]. LEDs can be selected to target the wavelengths used by plants, enabling growers to customize the light produced, to enable maximum plant production and limit wavelengths that do not significantly impact plant growth. In hydroponically grown tomato plants, experiment shows significant effect of Red and Blue LED to marketable fruit and biomass production [7].

Growth and morphological parameters, including dry shoot mass, leaf count, stem diameter, hypocotyl length, leaf area, and chlorophyll concentration, have indicated the benefit of supplemental lighting, especially under low DLI, but there were no significant differences among different red : blue ratios regardless of DLI [8]. Ultra-violet (UV) and blue radiations are perceived by plants through several photoreceptors. They regulate a large range of processes throughout plant life. Along with red radiations, they are involved in diverse photomorphogenic responses, e.g., seedling development, branching, or flowering [9]. Plants have evolved and specialized pigment-protein complexes, commonly referred to as photoreceptors, to capture light energy to drive photosynthesis, as well as to respond to changes in light quality and quantity. Blue light can act as a powerful environmental signal regulating phototropism, suppression of stem elongation, chloroplast movements, stomatal regulation, and cell membrane transport activity [10].

The research will design artificial grow light which has 6 types of light wavelength for plant growth. The designed system can set wavelength individually and has built-ins timer based on RTC for better timing accuracy. User can control all grow light features from Android application which runs in tablet.

2. Research Method

Figure 1 is system block diagram, where there are 6 different types of LED. Each LED is connected to constant current driver that has maximum current capacity of 700 mA. This driver has PWM pin for dimming function, and all PWM pin are connected to ESP8266 microcontroller, so the system can control each LED intensity. To measure light and clock accuracy, the system is equipped with TSL2561 light sensor and DS3231 Real Time Clock, where both modules have I2C pin that directly connect to ESP8266. ESP8266 is a Wi-Fi microcontroller that has built-in antenna and is able to connect to Wi-Fi router. System will connect to local MQTT broker which run in BananaPi single board ARM Linux, while the data is stored in InfluxDB database. System monitoring is provided by Grafana software, where all the software is open source and run in Linux operating system.

![Figure 1. Block Diagram of Grow Light System](image-url)
The LED driver used is intended for LEDs that have 3 W specifications, but the LED configuration uses a 1 W LED, hence the application of the current must be divided by stringing the LEDs that are divided into two with the aim of parallelizing the two circuits so that each gets half of the total current. This application is done only for LEDs which produce blue, red, full spectrum purple, and full natural white spectrum, while for LEDs that produce far red and ultraviolet light are configured directly without parading because they use 3 W LEDs.

Users can control LED lights using a PC/Tablet. Users will choose the intensity percentage they want to turn on and will the LED starts and stops. Data that has been selected by the user will then be processed with the intensity according to user input. Furthermore, the system will detect whether the current time has shown when the LED lights are set to off, if true, the royal blue LED lights will be turned off.

The system that has successfully connected to the specified Wi-Fi network will read the latest data on the MQTT server. If there is no new data coming in, the system will detect whether the latest data has entered the hour and minute to turn on the LED light. The system flow diagram is shown in Figure 3.

The system will detect whether the data is from royal blue LED or not. If the data is royal blue, then the system will continue to try connecting to the Wi-Fi network until it connects.

If the system has successfully connected to the specified Wi-Fi network, it will read the latest data from the MQTT broker and put on each variable (dataPwm, dataJam1, dataMenit1, dataJam2, and dataMenit2). The system will check for every LED spectrum.

Figure 2 shows the flow diagram of the system. When the system is turned on, the first thing the system will do is initializing the shelter variables, such as the value of the PWM, the value of time (hours and minutes), the value of data collection from TSL2561s, and others. Then, the system will turn off all LED lights. This is done in the beginning of the initialization so that all LED lights initial state are set to off. The system will then try to connect to the specified Wi-Fi network. If it does not connect, the system will continue to try connecting to the Wi-Fi network until it connects.

The system that has successfully connected to the specified Wi-Fi network will then process the data by viewing which data is received through which topic.

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Figure 2. Grow Light Flow Chart

Figure 3. Flow Chart of Blue And Red LED without New Coming Data
Figure 4. Flow Chart of blue and red LED with new data

Figure 4 is a system flow diagram that starts if there is a new data entered. The system will see whether the data came from the blue topic. If the data is blue data, then the life value of the LED light is equal to the value of current hour and minute. If it is the same, then the LED light will be turned on according to the intensity entered by the user, otherwise it will return to the main flow chart, but if it is true then the lamp will turn on. The system will detect whether the current time value has shown the time for it to turn off. The new data will be checked for every LED spectrum.
3. Result and Discussion

Table 1. Led Lens Type vs Light Intensity

| Lens Type | Information                  | LED 3 watt | LED 1 watt |
|-----------|------------------------------|------------|------------|
|           | PPFD in the middle (µmol m⁻² s⁻¹) | PPFD in the edge (µmol m⁻² s⁻¹) | PPFD in the middle (µmol m⁻² s⁻¹) | PPFD in the edge (µmol m⁻² s⁻¹) |
| Without   |                               |           |            |
| 5         | 6.21                          | 5.37      |
| 10 diameter 14.5 mm | 72.2               | 5.37      |
| 15        | 52.34                         | 3.00      |
| 30 small clear | 43.32               | 0.00      |
| 45 small clear | 43.33               | 0.00      |
| 60 black  | 14.27                         | 0.00      |
| 60 (60 Plano Convex) | 59.7               | 0.00      |
| 60 small clear | 33.34               | 0.00      |

Based on all the data that have been taken using twelve different lenses, it can be concluded that the lens used in the configuration is a 60-degree black lens. This lens is selected because the results of the distribution of this lens is quite large, namely in a diameter of 35 cm with the results of the difference in light intensity between the middle and edge values of 4.27 µmol m⁻² s⁻¹ for 3 watt LEDs and 1 watt LED 5.54 µmol m⁻² s⁻¹.

Figure 5. 60 degrees Black Lens on 4 LEDs

The data obtained is the data of 4 x 1.-watt full spectrum LEDs arranged in series to form a square, where LEDs are placed at each vertex with a distance between LEDs is of 5 cm configuration 2x2 LEDs. The PPFD value in each square in the table is a representation of the value of PPFD on a surface with a 5x5cm plane. The measurement of the intensity value is carried out at 30cm from the light source and carried out on a box with a light reflector on its side. This test is carried out to determine the intensity value if four LEDs are combined using the same lens, thus showing the intensity results.

Figure 6. Light distribution of the Deep Red LED lights in grow chamber 1 and 2
Figure 6 is the result of measuring the distribution produced by a deep red LED with an intensity of 100%. Based on the Figure 6, it can be concluded that the results of the distribution of the Deep red LED lights are quite even with the difference between the highest and lowest values is at the value of 9.12 µmol m\(^{-2}\)s\(^{-1}\). The Deep red LED lights produce even distribution due to a more precise configuration compared to the configuration used in the Royal Blue LED lighting configuration.

![Figure 6](image)

|   | D   | C   | B   | A   |
|---|-----|-----|-----|-----|
| 4 | 50.2 | 92.77 | 107.5 | 102.9 |
| 3 | 32.5 | 89.3 | 80.1 | 97.5 |
| 2 | 47.6 | 94.3 | 50.5 | 82.5 |
| 1 | 37.03 | 38.4 | 50.48 | 50.46 |

Figure 7. Light distribution of the royal blue LED lights in grow chamber 1 and 2

Figure 7 is the result of the distribution of royal blue LED lights that are turned on with a value of 100% intensity in each chamber. Based on the data in Figure 7, it can be concluded that the results of the distribution are not evenly distributed as those produced in first chamber. The distribution of the royal blue LED lights in second chamber has similarities, where in line D the results of the intensity are not as large as compared to the other lines. The comparison of the lowest value and the highest value in this distribution is also quite high, worth of 69.01 µmol m\(^{-2}\)s\(^{-1}\), even though it is not as big as in the first chamber which is 75 µmol m\(^{-2}\)s\(^{-1}\). Based on the results of the uneven distribution of light, it requires a further search for better configurations to produce a more even distribution.

![Figure 7](image)

Figure 8. Comparison of actual PPFD charts with PPFD from average conversion factor data

By taking the average conversion factor of each type of LED color, the following conversion value of the factor can be applied to the system:

- Nature White: 65.6014
- Royal Blue: 99.0074
- Far Red: 151.657
- UV: 112.465
- Deep Red: 50.3426
- Full Spectrum: 57.1289

Thus, the value of the intensity of the LED measured by the sensor TSL2561 is then calculated by the conversion factor obtained will result in the PPFD value. (measurement results of TSL2561 / factor conversion)

In the calculation of conversion from lux to PPFD on natural white LED lights, based on the data that has been obtained, the conversion factor is 65.6. The average error of the conversion data is 0.050642%. This small error value can also be seen in Figure 8, as shown by a line that is quite similar between the actual PPFD line and the conversion PPFD line. Error average of each type of color:
After obtaining the factor coefficients for one type of light, we look for conversion factor when two different types of light are emitted simultaneously. In this experiment there are two methods that we use to get the PPFD value from the actual lux value. In the first method, we look for the conversion factor of each mixing of two types of light in a device with PWM intensity from 100% to 50%, for each type of light. While in the second method, we add the lux value of one type of light divided by the conversion factor with one other type of light whose lux value is also divided by the conversion factor, then we compare the two added calculations with the reference PPFD value when the two lights are emitted simultaneously.

![Figure 9. Graph of mixing deep red and far red light](image)

From Figure 9, the second method shows that the reference PPFD values never intersect with the PPFD value of the TS12561 sensor. Also, the value of the percentage difference is greater when compared to the first method. Although the first method is better than the second, the first method reaches a percentage difference of 4.59%, so the second method combined with the first method cannot be applied to the system.

From the results of the tests that have been conducted, it can be concluded that the first method is better than the second method because more light mixing using the first method produces better results than using the second method. However, the two methods cannot be applied for mixing two types of light, because by using both methods, the possibility to convert lux values to PPFD values by mixing two lights require another factor that we have not found. We hope that further research will be done to find this combined conversion factor.

![Figure 10. Graph of ultraviolet LED spectrum wave](image)

The measurement results show that the LED that produces ultraviolet light emits the highest value spectrum at 420 nm, so the LEDs used in this system are not ultraviolet LEDs. The LED used in this system is a blue LED that has a 420 nm spectrum. As shown in the Figure 10, this LED only produces light below the 400 nm spectrum.
Conclusions
The lens affects the value of the intensity and so does the size of the light distribution diameter emitted by the LED. A lens that has excellent influence is a 60-degree black lens with a high intensity, with the intensity value that is more even compared to other lenses. The result of the distribution of the 60-degree black lens is 35 cm in diameter and the difference in the distribution value is 4.27 μmol m$^{-2}$s$^{-1}$. The best lens used is a 60-degree black lens, because it produces a high intensity with sufficient distribution diameter. The distribution results of this configuration are 230-236 μmol m$^{-2}$s$^{-1}$ with a distribution in the area of 10×10 cm$^2$. The grow light which can produces the most even value is the configuration of two types of deep red and natural white lights because the highest value and the lowest value difference of the two configurations is smaller than the four other types of configurations namely full spectrum, Far Red, royal blue, and ultraviolet. Highest PPFD value can be seen based on the data as a configuration of the royal blue lamp with the highest PPFD value at 107.5 μmol m$^{-2}$s$^{-1}$. From the results of the light spectrum testing, it can be concluded that the resulting spectrum is not in accordance with the specifications, especially on LEDs that produce ultraviolet light due to a difference of 20 nm from the specifications. LEDs that produce red, blue, full spectrum, natural white, and far red light produce a spectrum that differs slightly from the specifications. Germination process for lettuce show no big difference result compare to sunlight.

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References
[1]  Kozai T, Fujiwara K, Runkle E S 2016 LED Lighting for Urban Agriculture *Singapore: Springer Science+Business Media."
[2]  Darkó É. Heydarizadeh P, Schoefs B, Sabzalian M 2014 Photosynthesis under artificial light: The shift in primary and secondary metabolism *Philosophical transactions of the Royal Society of London Series B, Biological sciences* 369
[3]  Snowden M, Cope K, Bugbee B 2016 Sensitivity of Seven Diverse Species to Blue and Green Light: Interactions with Photon Flux *PLOS ONE* 11
[4]  Bantis F, Ouzounis T, Radoglou K 2016 Artificial LED lighting enhances growth characteristics and total phenolic content of Ocimum basilicum, but variably affects transplant success * Scientia Horticulturae* 198
[5]  Byun A, Mao M, Sidhu R 2013 The Effect of Different Wavelengths on The Germination time of Arabidopsis thaliana wild type and mutant type seeds *The Expedition Vol 3*
[6]  Demotes S, Péron T, Corot A, Bertheloot J, Gourrierec J, Travier S, Crespel L, Morel P, Huché L, Bowmaza R, Vian A, Guérin V, Leduc N, Sakr S 2015 Plant responses to red and far-red lights, applications in horticulture *Environmental and Experimental Botany* 309
[7]  Deram P, Lefsrud M, Orsat V 2014 Supplemental Lighting Orientation and Red-to-blue Ratio of Light-emitting Diodes for Greenhouse Tomato Production *HortScience* 49
[8]  Hernández R, Kubota C 2012 Tomato seedling growth and morphological responses to supplemental LED lighting red:Blue ratios under varied daily solar light integrals *Acta Horticulturae* 956
[9]  Huché L, Crespel L, Gourrierec J, Morela P 2016 Light signaling and plant responses to blue and UV radiations - Perspectives for applications in horticulture *Environmental and Experimental Botany Vol 121 pp 22-28*
[10] Kopsell D, Sams C, Morrow R 2015 Blue Wavelengths from LED Lighting Increase Nutritionally Important Metabolites in Specialty Crops *HortScience* 50