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A Simple Wireless System for Monitoring PAR and Remotely Control Intensity in Smart Farming

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Abstract

In every growth-stage, a plant requires a different amount of PAR intensity for photosynthesis. The light irradiance is not only obtained from sunlight but can be manipulated using LED in an enclosed cultivation room. Each LED has a different value of Photosynthetically Active Radiation (μmol/m^{2}s) although they have the same irradiance in Lux. In this paper, a simple wireless system for PAR monitoring and remotely control intensity was built using silicon-based photo transistor sensor, controller and an Android application which is able to adjust the brightness of the three LEDs as desired from distance. The peak wavelengths of the three LEDs are 617 nm (red), 465 nm (blue), and 520 nm (green). The system is able to record irradiance in Lux and PPFD (μmol/m^{2}s) of PAR spectrum. Compared to the commercial PAR-meter, the system has good measurement accuracy in red room, blue room and green room are 99.64%, 97.61%, and 99.58%, respectively. The opened-loop irradiance control system for cultivation room also has a good response dynamic. the red LED has the shortest rise time of 2.95 second and the low error steady state than others, 2,33 Lux. It means, the red LED control system can give a quick response and good stability irradiance. In the other hand, the green LED has the highest rise time fo 3.7 second and the highest error steady state of 12,95 Lux, compared to the other LED. The green LED control system can do slower response to reach its maximum irradiance and the worst stability performance while irradiating the cultivation room.

Keywords — PPFD measurement, Photosynthetically Active Radiation, PAR monitoring system, Opened-loop irradiance control system

Introduction

The unit of light intensity is already known as Lux. Meanwhile, in agriculture, there is a spectrum of light which is needed by plants to execute photosynthesis, it is called Photosynthetically Active Radiation (PAR). The PAR spectrum covers the visible light in a range from 400 nm to 700 nm [1]. The amount of PAR is also expressed as the quanta of electromagnetic radiation, Photosynthetic Photon Flux Density (PPFD) in units of µmol/m^{2}s [2]. In every-phase of growth, a plant requires varying amounts of PAR for photosynthesis. Increasing the irradiance of PAR can promote plant growth-rates because photosynthesis process runs well [3][4]. Otherwise, deficiency or excess of PAR radiation during the cultivation can effect etiolation symptoms which is indicated by long stems, smaller leaves and pale colors [5]. For example, tomato plant (Silanum lycopersicum) needs PAR irradiance of 50-550 µmol/m^{2}s [6], basil (Ocimum basilicum L) needs 200-250 µmol/m^{2}s [7] and cannabis (Cannabis sativa) needs 600-900 µmol/m^{2}s [8]. Although this parameter plays important role in agricultural production and biotechnology [9], it is often not measured well [10] because the PAR irradiation is depends on weather and climate condition [11].

In every growth-stage, plant requires varying amount of PAR irradiation requirement. In case of cannabis, the propagation stage needs low PAR for two weeks to establish new root systems. In the vegetative stage, it needs higher PAR exposure than prior stage for 4 weeks. Then in flowering stage, it requires most high PAR irradiance until harvesting period [8]. To ensure the intensity meets the needs of every-growth-stage, it is important to monitor and control the amount of PAR in the plant's cultivation rooms. Nowadays, the Lux-meter is the most common instrument for measuring the intensity of light. Unfortunately, it is not suitable for measuring intensity in PAR Spectrum.

Several methods have already developed by prior researchers for measuring PAR [12]. In 2014, Barnard et al. designed a low-cost PAR intensity monitoring system using an Arduino microcontroller, and later the device was named PARduino. This tool uses a LI-COR quantum PAR sensor which is equipped with a real-time clock component and still using a micro SD to store data record [13]. Later, a system using Raspberry Pi and Arduino was proposed to processed PAR value from light sensors. The collecting data of average PAR value was displayed on LCD including the time information. Many PAR sensors were invented in by researchers, starting from modificating photodiode with optical filter and diffuser [14] to enhancing blue silicon photodiode with an 8 mm substrate protective casing coated with infra-red filter [12]. Another PAR sensor has also proposed using printed circuit board with the three spectral sensor ICs, a plastic enclosure and a light diffuser [15]. Arnaud Coffin et al. presented a device named PARADe in 2021, it was an acquisition of PAR irradiance using commercially PAR quantum sensor (PAR/LE, SOLEMS), Android as a microcontroller and equipped with a solar panel as a power source for the device. Remote data acquisition via internet or wireless communication will be developed in the future [11].

The several studies above use the same external memory in storing data from the PAR sensor readings, so it requires an additional device to download the data recorded on the Micro-SD, the process is not efficient to monitor the PAR irradiance time by time. The commercial PAR-meter does already exist, but expensive[16]. Neither PAR-meter nor the several mentioned-prior research are unable to monitor from a distance.

In this research, we are not only developing monitoring system for PAR irradiation in cultivation room, but also opened-control system to adjust the LED irradiance level as desired to meet the needs of PAR irradiance in every-growth-stage of plants. Light Emitting Diode (LED) have been used as source of light in the cultivation room, because it does not emit high temperatures for the plants [17]. There are three visible lights which have effect on plant growth, i.e. red (600-700 nm), blue (400-500 nm) and green (500-600 nm). Most of the red light is absorbed by chlorophyll for photosynthesis which affects photoperiodism [5]. Blue light is as less-efficiently absorbed by chlorophyll as red but inhibit etiolation of plant and be able to promote branching of the plant [18]. Meanwhile, the green light is less-influenced spectrum on photosynthesis and cell formation of plants [4].

The present research aims to develop a simple system for monitoring and controlling the PAR irradiance by LED using an android application. Radiation in PAR spectrum detected by the sensors then induce current as its output. The output current has a linear relationship to PPFD value (μmol/m^{2}s) [13]. This system consists of three light intensity sensors, a controller, in-room LCD display, and Android applications for wireless monitoring and control. The results of this research are conferred and rationalized in terms of dynamics response as the performance of the control system and the characteristic of the monitoring system.

Control system commands are executed through the Android application. Users can adjust the LED irradiance level in the cultivation room as desired. The prior research has been successfully adjust the irradiance using pulse width modulation (PWM) but unable to do from distance [19]. The novelty of this research is to monitor PAR and control the irradiance remotely from the distance, so user needs to connect the system to Wi-Fi easily.

Methodology

Hardware Design and Manufacturing

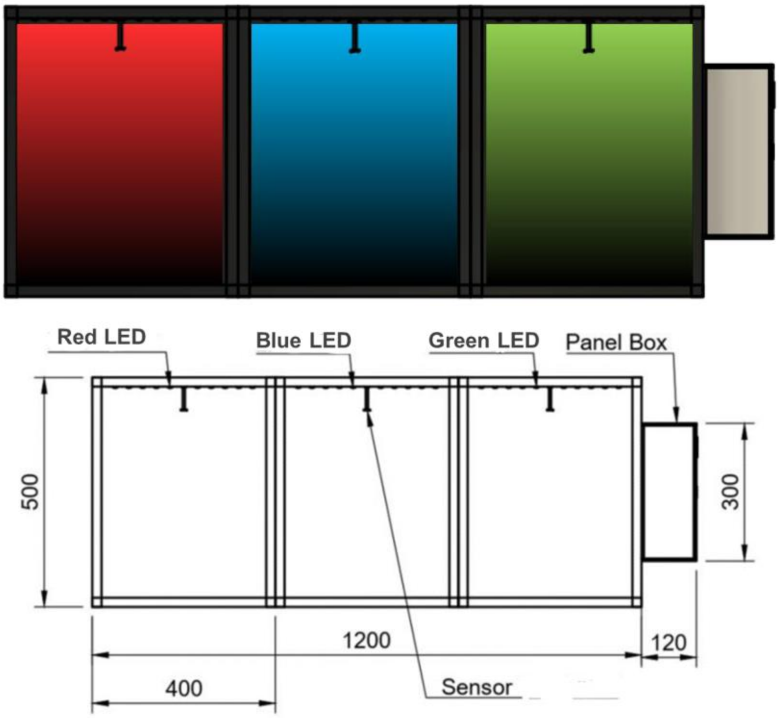

Figure 1. *Dimensions of cultivation room*

This experiment system consists of three cultivation chambers which is exposed by different spectrum of LED, i.e., red, blue and green (Fig 1). Each room has the same dimension, 200 cm^2 of cross-sectional areas and height of 50 cm. The LED as the light source is placed under the ceiling room. The sensors are placed 5 cm below the LED on the cultivation room. It is also attached with a panel box for microcontroller and its electrical circuits.

Block diagram for LED irradiance level is showed by figure 2. User can set the desired irradiance level through android application and be received by NodeMCU ESP32 controller. Pulse timing control of PWM can adjust or dimming the LED in the cultivation room.

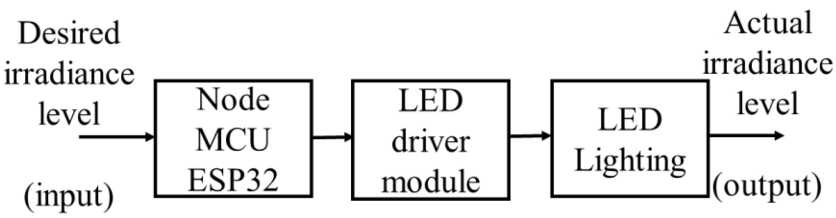

Figure 2. *Opened-loop control System Block Diagram for LED irradiance level*

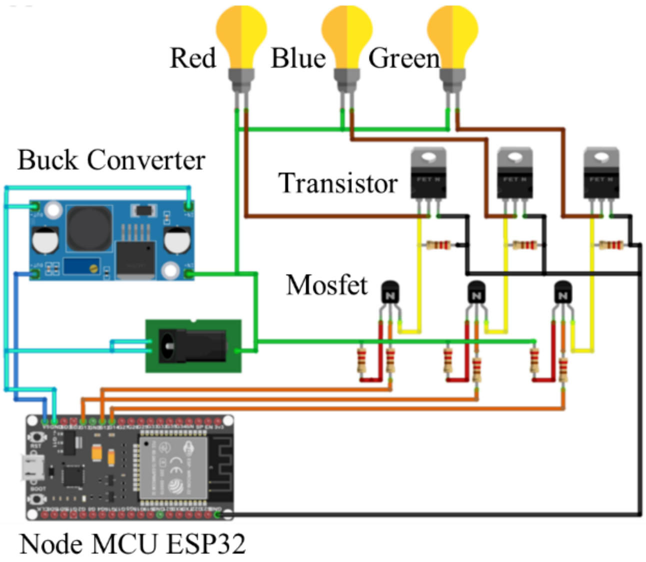

Figure 3. *Simplified wiring diagram for adjustable LED*

Figure 3 shows the wiring diagram of this opened-loop control system. The electrical circuit consist of a buck converter module to reduce the voltage from 12 VDC to 5 VDC. The lower voltage will be connected to the V_{in} pin of the NodeMCU ESP32. There are three transistors to amplify the output of the NodeMCU ESP32 so it would be higher than 3.3 VDC while connected to mosfet.

For the irradiance monitoring system, the block diagram is showed by figure 4. LED strip SMD5050 are used as a light source in this cultivation room. They are red (610-625 nm), blue (460-470 nm) and green (515-525 nm). The light sensors we used in this system are silicon planar phototransistor which is sensitive to 440 – 800 nm because based on the prior experiment, the kind of silicon sensor has high sensitivity of light [20]. The irradiance is sensed by the sensor which is indicated by varying output voltage as its response. The output processed by the NodeMCU ESP32 controller then displayed on the LCD and the Android Application in unit of Lux and PPFD. To convert Lux to PPFD (μmol/m^{2}s), we measured output voltage and took place a commercial Luxmeter and PAR-meter in the same position with sensor. We varied the brightness of each LED by 10 variations and measured repeatedly of 5 times.

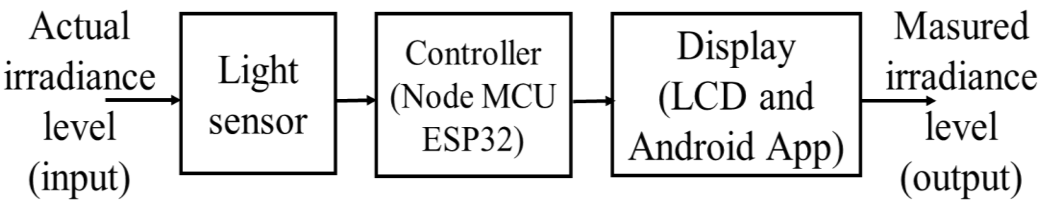

Figure 4. *Monitoring System Block Diagram*

Software and User Interface Design

Figure 5. *User interface on Android application*

In android application, users can monitor the real time irradiance in Lux and PAR for each room. They also can do adjustment to the LED by tapping the plus and minus button (Fig 5). We also provide three tabs which are used to control and monitor the selected rooms. The collecting data is also displayed on the time-based graph.

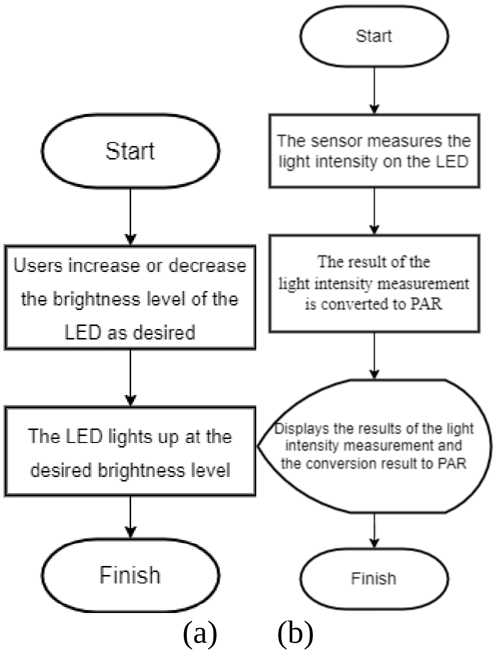

Figure 6. *System Flowchart for (a) opened-loop control and (b) monitoring system*

Results and Discussion

Correlation of Light Irradiance (Lux) to Photosynthetically Active Radiation (PAR)

Each spectrum of visible light has a different conversion factor value to show the correlation irradiance expressed in Lux and PAR. The conversion equation from Lux to PAR is obtained from the monitoring data compared to commercial Luxmeter and PAR-meter.

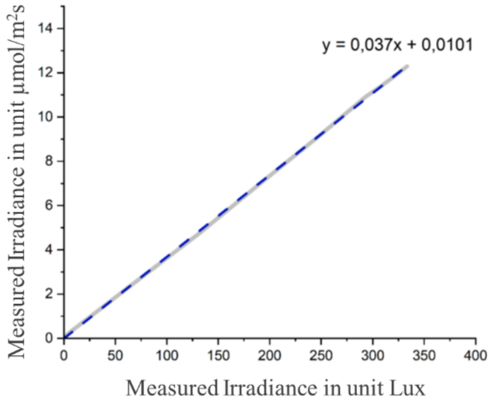

Figure 7. *Correlation graph of measured irradiance in lux to PAR for red LED*

The measured irradiance in Lux has a linear relationship to PAR value (μmol/m^2s). According to figure 7, we found the conversion factor for red LED is 0.037. It showed by regression equation

$$\mathrm{PAR_{red}} = 0.037\ \mathrm{Lux} + 0.0101$$

It means, 1 Lux of red LED is equal to 0.0269 μmol/m^2s.

The similar graphic trend is obtained for blue and green LED. They also have a linier correlation between irradiance in Lux and PAR (μmol/m^2s). Figure 8 to 9 show their conversion factor.

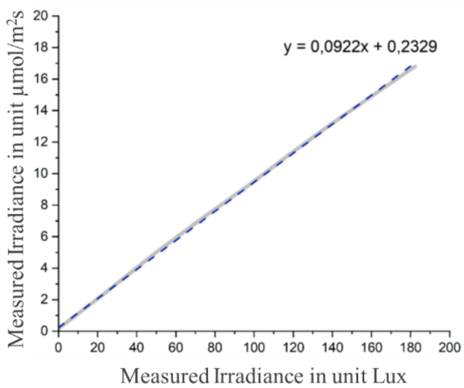

Figure 8. *Correlation graph of measured irradiance in lux to PAR for blue LED*

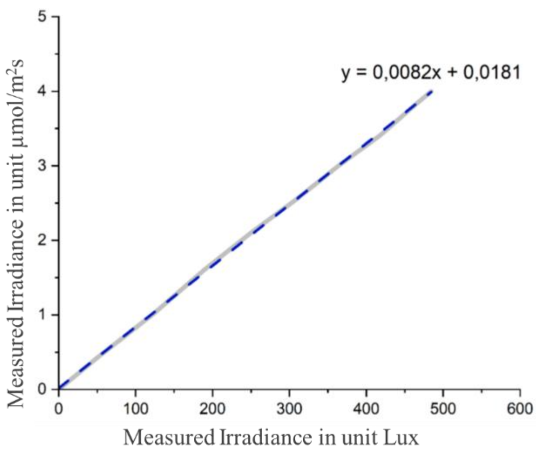

Figure 7. *Correlation graph of measured irradiance in lux to PAR for green LED*

Based on the experiment result which is showed in figure 8 and 9, the conversion factor for blue and green LED is 0.0922 and 0.0082, respectively. The showing regression for blue and green are expressed by equation below:

$$PAR_{blue} = 0.0922 \text{ Lux} + 0.2329$$
$$PAR_{green} = 0.0082 \text{ Lux} + 0.0181$$

They mean, 1 Lux of blue LED is equal to 0.3251 µmol/m^{2}s and 0.0263 µmol/m^{2}s for green LED.

Opened-Loop Control System Performance

The brightness level of the LED can be remotely controlled by user from distance through the Android application. The step button has been provided on user interface so user can increase or decrease the irradiance in every cultivation room. To determine the performance of the opened-control system, we set irradiance of each LED to their maximum value. Then we collected the data from storage to identify rise time (t_r), settling time (t_s) and error steady state (E_{ss}) to observe the irradiance stability. The results of control system performance test are shown in the figure 10-12 as follows.

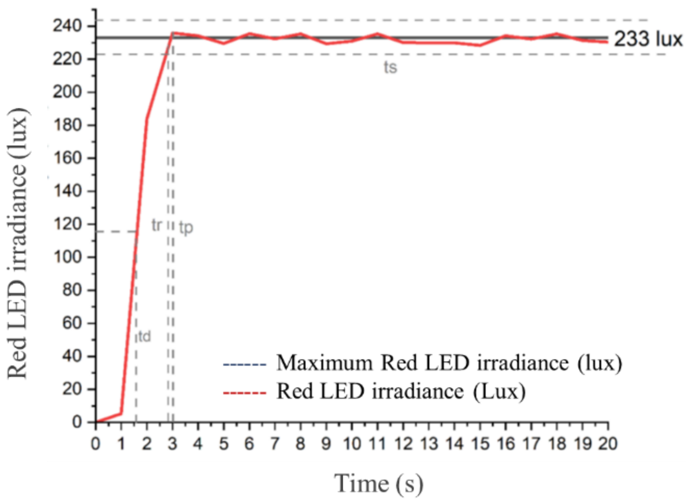

Figure 10. *Dynamic response system graph of opened-loop control for red LED to reach its maximum irradiance*

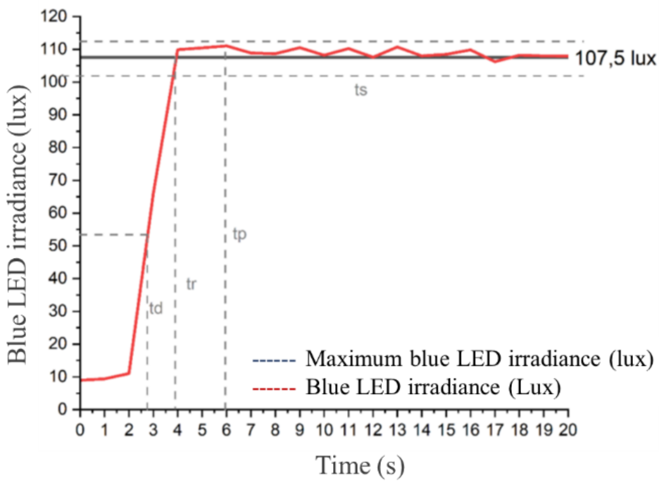

Figure 11. *Dynamic response system graph of opened-loop control for blue LED to reach its maximum irradiance*

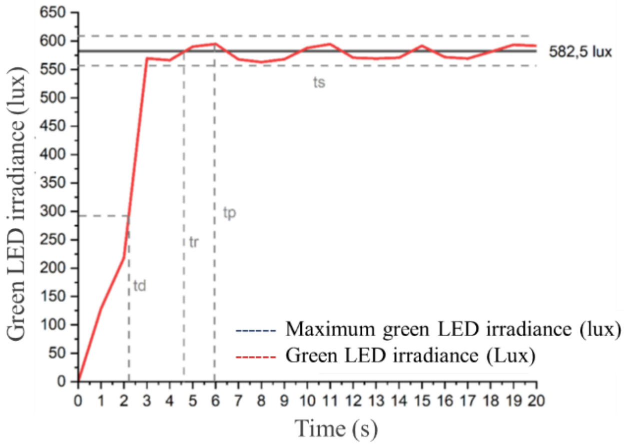

Figure 12. *Dynamic response system graph of opened-loop control for green LED to reach its maximum irradiance*

Rise time (t_r) indicates the time which is required to rise from LED off to the maximum irradiance. Settling time (t_s) show us about the time required for system to reach and steady within a given tolerance value of its maximum irradiance. Error steady state (E_{ss}) is defined as the difference value of maximum irradiance with the measured irradiance of the LED.

Table 1. *Performance of opened-loop control system of each room based on its dynamics response parameters*

	Red (610-625 nm)	**Blue (460-470 nm)**	**Green (515-525 nm)**
Maximum irradiance (Lux)	233	107,5	582,5
Rise time (s)	2,95	3,95	4,7
Settling time (s)	3	4	3
Error steady state (Lux)	2,33	2,16	12, 95

Maximum input voltage has been applied to each LED to reach their maximum irradiance. The measurement of maximum irradiance showed the difference value, although have the same input voltage. The red, blue and green LED has 233 Lux, 107,5 Lux and 582,5 Lux, respectively. According to experiment result, the red LED has the shortest rise time of 2.95 second and the low error steady state than others, 2,33 Lux. It means, the red LED control system can give a quick response and good stability irradiance. In the other hand, the green LED has the highest rise time fo 3.7 second and the highest error steady state of 12,95 Lux, compared to the other LED. The green LED control system can do slower response to reach its maximum irradiance and the worst stability performance while irradiating the cultivation room.

Conclusions

In this research, a simple wireless system for monitoring PAR and remotely control in smart farming was successfully constructed. Firstly, The PAR monitoring system performance is excellent compared to the commercially PAR-meter. It showed by the accuracy of monitoring in red room, blue room and green room are 99.64%, 97.61%, and 99.58%, respectively. Secondly, the conversion factor to convert irradiance from Lux to PPFD unit (μmol/m^{2}s) has been find out, i.e 0.037 for red light, 0.0922 for blue light and 0.0082 for the green light. The opened-loop irradiance control system for cultivation room also has a good response dynamic. the red LED has the shortest rise time of 2.95 second and the low error steady state than others, 2,33 Lux. It means, the red LED control system can give a quick response and good stability irradiance. In the other hand, the green LED has the highest rise time fo 3.7 second and the highest error steady state of 12,95 Lux, compared to the other LED. The green LED control system can do slower response to reach its maximum irradiance and the worst stability performance while irradiating the cultivation room.

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