Journal of Engineering and Applied Sciences 13 (3): 541-545, 2018
ISSN: 1816-949X

Eco-Friendly LED Plant Factory Development

[1]Bonghwan Kim, [2]Dongin Lee and [1]Kyunghan Chun
[1]Department of Electronic and Electrical Engineering,
Catholic University of Daegu, 38430 Gyeongbuk, Korea
[2]Department of Information and Communication Engineering,
Yeungnam University, 38541 Gyeongbuk, Korea

Abstract: Plant factories are cultivation facilities that enable year-round production of vegetables and other products by allowing precise control and monitoring of cultivation conditions and plant growth. This study examines the use of artificial-lighting sources for indoor photosynthesis and proposes a novel indoor plant-lighting scheme. And this study is also focused on the research of the energy saving technology for household dissemination of plant factory through using artificial light source. For eco-friendly purpose and long life time, electrolytic capacitor-less Switched Mode Power Supply (SMPS) is designed and Power Factor Correction (PFC) type one stage Light Emitting Diode (LED) driver is also developed. Dimming control is applied to make efficient electric current consumption for saving energy and the used high frequency improves flickering. The developed plant factory is tested for the lettuce and the optimization of the light timing and distance is accomplished for better production.

Key words: Indoor farming, plant factory, LED, energy saving, dimming, Korea

INTRODUCTION

Since, the agriculture is influenced by the climate, soil and the environment, the plant factory using an artificial light is magnified because of some problems including limited cultivation by seasonal reason and the stability of food by pesticide usage. For the purpose of higher productivity, most plant factory control the optimum condition for growth of plant including light, temperature, water and nutrition. And they are also preparing the hermetically sealed form that is available to provide stable plant in response to the climate change and damage by disease and insect (Lee, 2010).

In recent years, enclosed plant factories using artificial light have been used to produce crops in a highly efficient manner (Goto, 2012). Such plant factories can provide optimal growth conditions for plants with no influence from the external environment.

Optimization work to reduce turnaround time to obtain optimum output in plant factory is a major challenge in many developing and underdeveloped countries typically it was done in close environment. Problem associated with cultivation of vegetables crop under direct sunlight will eventually reduce its quality and indoor farming is the new approach to address this issue (Okuda *et al*., 2014). Close loop system approach or plant factory has been introduced recently to optimize the plant growth and to increase yield and flowering control (Morimoto and Hashimoto, 2000).

Sunlight conveys all the energy consumed on earth. Photosynthesis on plants is the most important manner to store sunlight energy and transform them into the nutrients needed by the plants. Among the solar energy, within the range of 400-700 nm light spectrum, e.g., visible light range can provide the most important energy for plant photosynthesis. This range of spectrum is called Photosynthetic Active Radiation (PAR) (Smith, 1975).

To mimic this part of sunlight, many researches are performed to supply stable light supply for in-house farming (Folta *et al*., 2005; Miyashita *et al*., 1994; Bula *et al*., 1991; Jao and Fang, 2004; Chen, 2005; Feng *et al*., 2005; Fang and Jao, 1996). On the other hand, fluorescent lamps are also applied by many biotechnical companies (Chen, 2005; Feng *et al*., 2005; Fang and Jao, 1996). Fluorescent lamps provide better sun-like spectrum the red light spectrum is not sufficient for fluorescent lamps. Besides, since, the diming of fluorescent lamps needs extra devices, lamps are basically on/off operated to provide different light intensity.

In this study, a plant factory with eco-friendly LED lights is proposed. The dimming controller is designed for saving the electric power and ensures the crop

Corresponding Author: Dongin Lee, Department of Information and Communication Engineering, Yeungnam University, 38541 Gyeongbuk, Korea

productivity. The lifetime of the LED and LED driver is also improved by designing a new SMPS without electrolytic capacitor. For better production, light timing and light distance are considered as variables to be optimized and the reflecting plate is also applied to enhance the lighting efficiency. The plant factory is developed through several prototypes and the final model is used to test. The test for lettuce cultivation shows good results of the proposed plant factory.

MATERIALS AND METHODS

LED plant factory: Plant factory is a system which artificially controls the environmental conditions of light, temperature, humidity, carbon dioxide concentration, culture fluid and so on. Plant factory cultivates crops through the environmental control and automation, regardless of season or the location. LED plant factory uses LED as the light source. For LED light system, SMPS and dimming controller are required. SMPS supplies the electric power and dimming controller is for the brightness control.

In SMPS of the light system, capacitor is used for storage to deliver a lot of energy and its price is cheap. It is easy to make into a small size in the case of the capacitor. LED lights are powered by direct current which should in many cases be used in the electrolytic capacitor of the high-capacity output stage. But the capacitor is a lethal factor because the life of the capacitor is very shorter than the LED device, interfering with the great advantage of the long-life LED light. Therefore, for making long-life LED light system, we develop SMPS without the electrolytic capacitor and design SMPS to achieve the specific target to have better performance than conventional products.

In addition for energy saving, we use dimming method for brightness control. Actually, the light is brightest when the light is on all the time. However, the most effective light condition of plant production is not guaranteed while the light is on. So, we find the proper dimming timing to improve crop production and also to save power consumption by lab test.

Long life SMPS: To have long life, we remove electrolytic capacitors from SMPS and this improves the high temperature property of SMPS and results in long life over 50,000 h. After removing electrolytic capacitors, we design the optimal RC filter to provide the constant electric current and current feedback loop is also applied in the circuit design to control the constant electric current. To enhance the reliability of the SMPS, the Over Voltage Protection (OVP) and Over Current Protection (OCP) circuits are also implemented in the circuit design. To minimize the Electromagnetic Interference (EMI) from the SMPS, a filter is designed and added. The proposed structure is shown in Fig. 1.

Figure 2 shows the differences between the conventional and proposed SMPS. The yellow circles in Fig. 2a indicate the electrolytic capacitors used in the conventional SMPS.

Dimming control: We propose variable dimming controllers which can be tuned for the effective plant growth. For variable dimming, the Pulse Width Modulation (PWM) is applied to supply electric power to the LED. For the practical usage, 4 types of dimming are selected and the required hardware is developed and the software is also programmed in C language. Four types dimming are as shown in Table 1. Type 0 is constant lighting and gradually on time is decreased and the actual amount of light is also reduced. In other words, 4 types mean 4 levels of the brightness.

Also for removing flickering, the PWM frequency of the proposed dimming controller is increased than that of the conventional one. This basically improves the consistent light supply without flickering to the plant.

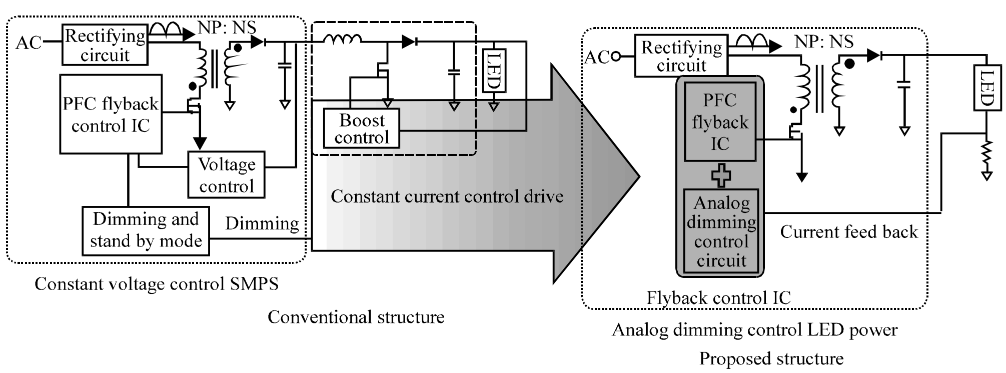
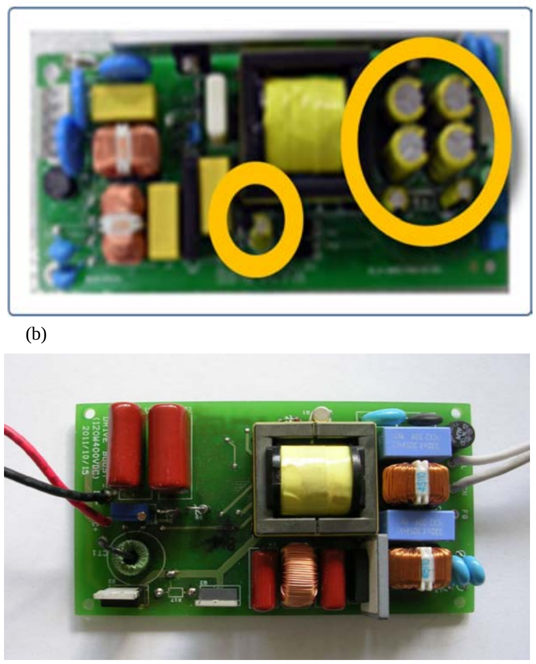


Fig. 1: Proposed structure

(a)



(b)

Fig. 2: SMPS: a) Conventional and b) Proposed

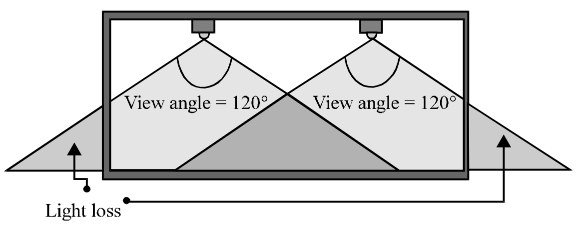


Fig. 3: Light loss in the plant factory

Table 1: Four type dimming

Dimming types	Frequency (cycles per sec)	On/Off time (usec)	Duty ratio (%)
0		400 µsec/0 µsec	0
1	2500	200 µsec/200 µsec	50
2	2500	100 µsec/300 µsec	25
3	2500	80 µsec/320 µsec	20

Reflecting plate: To improve light loss from each edge of the plant factory, reflecting plates on both sides are considered. Because bar type LEDs will be installed in parallel, the irradiation angle (view angle) is out of bound at edge as shown in Fig. 3 and it is light loss.

Therefore, the plant growth at the edge is degraded than the plant growth in the middle because of the difference of the light intensity. To improve plant growth, left and right reflecting plates are applied and the light saving is acquired as a result in Fig. 4.

In the same reason, the reflecting plate is also installed at rear side to increase the light efficiency and it can be verified by the mirror effect at each side.

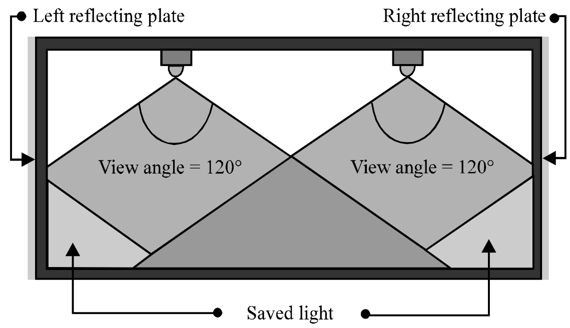


Fig. 4: Saving light by reflecting plates at each edge

RESULTS AND DISCUSSION

Test and validation: In this study, the developed bar type LED light and the mixed LEDs are chosen because the proper LED allocation is tested for the better production.

SMPS: Figure 5 shows the integrating test of LED and SMPS. The light is stable and the system works well. The final developed plant factory is portable as shown in Fig. 5b.

Dimming: For finding proper dimming timing to get the best yield, 4 test groups are selected and their dimming ratios are 0% (P1), 50% (P2), 25% (P3) and 20% (P4). Each group has 15 heads of lettuce Lollo and after test period the average yield of each test group is considered as yield index. The resulting lettuce picture is shown in Fig. 6.

At a first glance, P1 looks better than P4 and it means that the more light, the better lettuce. But to compare all together in the quantitative manner the value is required. So, we choose power dissipation per 100 g lettuce for showing the effectiveness of the lighting and the result of 22 days cultivation is shown in Table 2.

Even if using the same LED, the productivity of the plant factory is different by PWM control of the light and the result shows that the PWM control of the light is more productive than the conventional light ON all the time control. For example, P3 which has a duty ratio 25% is 4 times more effective in the power dissipation than P1 which lights on all the time and P3 is 3.7 times better in the productivity than P1 for the same power dissipation which can be calculated by yields per power dissipation.

Distance: For the same LED, the distance effects also are tested. Test groups are D1-D3 (10-30 cm) and 15 heads of lettuce Lollo of each group are cultivated under the same environment except the light distance for 36 days. Comparing D1 (718 g) and D2 (599 g), the difference of the average weight including roots is about 8 g which

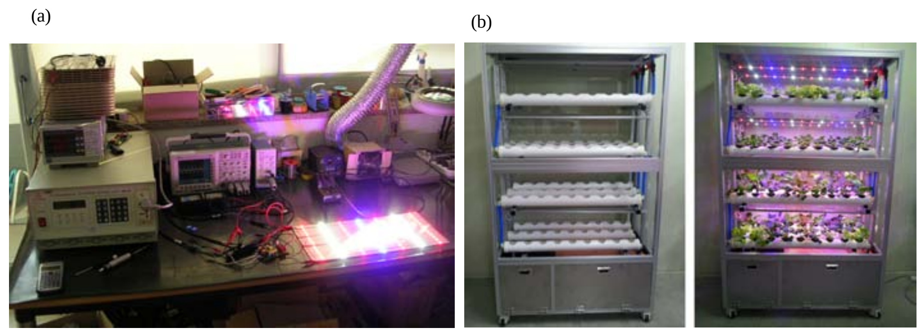


Fig. 5: SMPS test and final prototype: a) SMPS and b) Final prototype

Fig. 6: Lettuce crop: a) P1; b) P2; c) P3 and d) P4

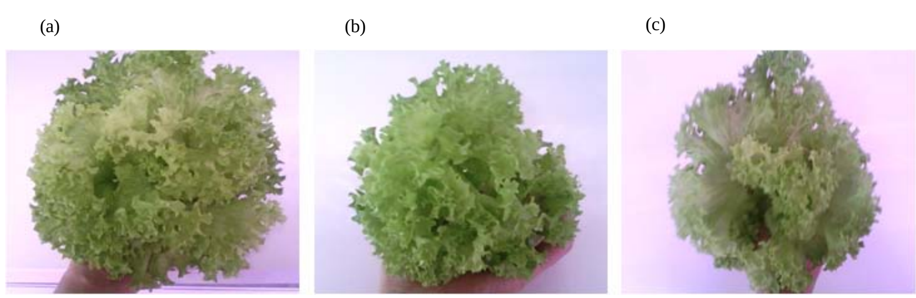


Fig. 7: Lettuce by lights located at different distances: a) D1-10 cm; b) D2-20 cm and c) D3-30 cm

Table 2: Showing the effective results

Test groups	Dimming ratio (%)	Power dissipation (kW)	Yields (g)	PD per 100 g (W/g)
P1	0	26.88	389	6.9
P2	50	13.44	371	3.6
P3	25	6.72	364	1.8
P4	20	5.37	325	1.6

can be calculated by (718-599)/15 and in leaf length the average difference is about 10-20 mm. The Photosynthetic Photon Flux Density (PPFD) equation also shows that the PPFD value is inversely proportional to the distance square, so, the closer in the distance, the better in the productivity. Figure 7 shows the yields of D1-D3.

Remark: If the LED module is too close to the plant, LED heat causes the leaf damage and the atmospheric congestion produces the degradation of the heat radiation.

CONCLUSION

In this study, the plant factory with LED light is proposed and the eco-friendly properties are contained by developing long life SMPS and applying dimming control by using PWM. The reflecting plate is also utilized to improve the light loss which is produced at the edge of plant factory because the radiation range of the LED light is wider than the width of the factory. Dimming timing and the distance are tested as variables for better production and by the tuned dimming timing, the power dissipation is decreased. In other words, the energy is saved and under the same energy, we find that the closer in the distance, the better in the productivity. Especially, the proposed plant factory is a portable type, so it can also be applied to the indoor cultivation.

ACKNOWLEDGEMENTS

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. NRF-2015R1D1A1A01059060). This research was also supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. NRF- 2016R1D1A3A03919627).

REFERENCES

Bula, R.J., R.C. Morrow, T.W. Tibbitts, D.J. Barta and W.R. Ignatius *et al*., 1991. Light-emitting diodes as a radiation source for plants. Hort. Sci., 26: 203-205.

Chen, C., 2005. Fluorescent lighting distribution for plant micropropagation. Biosyst. Eng., 90: 295-306.

Fang, W. and R.C. Jao, 1996. Simulation of light environment with fluorescent lamps and design of a movable light mounting fixture in a growing room. Proceedings of the International Symposium on Plant Production in Closed Ecosystems, December 1, 1996, ISHS Publisher, Narita, Japan, ISBN:978-90-66058-88-0, pp: 181-186.

Feng, C.Y., H.N. Feng and S.Z. Jin, 2005. The research of lamp for the growing of green plants. Proceedings of the SPIE Conference on Light-Emitting Diode Materials and Devices, January 19, 2005, SPIE Publisher, Bellingham, Washington, pp: 192-197.

Folta, K.M., L.L. Koss, R. McMorrow, H.H. Kim and J.D. Kenitz *et al*., 2005. Design and fabrication of adjustable red-green-blue LED light arrays for plant research. BMC. Plant Biol., 5: 1-11.

Goto, E., 2012. Plant production in a closed plant factory with artificial lighting. Proceedings of the 7th International Symposium on Light in Horticultural Systems, October 14, 2012, ISHS Publisher, Wageningen, Netherlands, ISBN:978-90-66055-45-2, pp: 37-49.

Jao, R.C. and W. Fang, 2004. Growth of potato plantlets in vitro is different when provided concurrent versus alternating blue and red light photoperiods. Hort. Sci., 39: 380-382.

Lee, S.W., 2010. Plant factory and plant cultivation using the LED artificial light. Opt. Sci. Technol., 14: 12-19.

Miyashita, Y., Y. Kitaya, T. Kozai and T. Kimura, 1994. Effects of red and far-red light on the growth and morphology of potato plantlets in vitro: Using light emitting diode as a light source for micro propagation. Acta Horiculturae, 393: 710-715.

Morimoto, T. and Y. Hashimoto, 2000. AI approaches to identification and control of total plant production systems. Control Eng. Pract., 8: 555-567.

Okuda, N., K. Toriyama, M.I.Y.A. Yuta, T. Yanagi and K. Yamaguchi *et al*., 2014. Effect of end-of-day light irradiation using LED light sources on the growth of lettuce under a high temperature. Environ. Control Biol., 52: 73-77.

Smith, H., 1975. Phytochrome and Photomorphogenesis: An Introduction to the Photocontrol of Plant Development. McGraw Hill Company, London, UK., ISBN-13: 978-0070840386, Pages: 220.