Internet of things based automated monitoring for indoor aeroponic system

Teuku Muhammad Roffi, Charisma Aulia Jamhari
Department of Electrical Engineering, Faculty of Industrial Technology, Universitas Pertamina, Jakarta, Indonesia

Article Info

Article history:

Received Jan 1, 2022
Revised Jul 18, 2022
Accepted Aug 13, 2022

Keywords:

Aeroponic
Internet-of-things
Light emitting diodes
Remote monitoring

ABSTRACT

On the ever-rising urgency of global food security, efforts are required to develop a robust farming technique. This includes the capability of farming in non-agricultural land or indoor spaces. Farming in the air medium, i.e., aeroponic, has persistently stepped in as a viable solution. Aeroponic farming allows efficient water usage while preventing soil related diseases and pests. With the assistance of light emitting diodes (LEDs) and precise electronic monitoring and control, aeroponic may become the suitable farming technique of the future. This work presents an aeroponic system capable of automated monitoring and control of farming parameters. The system achieved both robustness in indoor farming and remote access by employing LED as an artificial lighting system and the internet-of-things (IoT) connectivity, respectively. The test result demonstrated that the system successfully maintained the root chamber temperature below 30 °C with a typical average temperature of 28.8 °C. The system managed a humidity level which prevented plants from drying out. It was also evident that the LED assistance significantly improved the growth quality of *Ipomea reptans*. The system, data, and analysis presented in this work is expected to facilitate further development of a robust food production system in overcoming the global food crisis.

Corresponding Author:

Teuku Muhammad Roffi
Department of Electrical Engineering, Faculty of Industrial Technology, Universitas Pertamina
Jakarta, Indonesia
Email: teuku.roffi@universitaspertamina.ac.id

1. INTRODUCTION

Food security has been an inevitable issue for mankind. It is even more important in recent years due to the increase of global population, climate instability, and limited agricultural land [1]. With almost 8 billion global population, the Food and Agriculture Organization of the United Nations reported that at least 720 million people faced hunger in 2020 and 660 million people may still face hunger in 2030 [2]. Climate instability which brought drought and other disasters amplified the crisis. This has driven innovation towards a more robust agricultural technique.

Aeroponic farming is a highly promising solution to mitigate food security. Developed by NASA as a high-end space farming technique [3], aeroponic farming started to be adopted as one of urban farming methods. It is particularly interesting due to its nature of farming outside of the conventional agricultural land, efficiency in water consumption, as well as resiliency against soil-related-diseases and pests [4]. Aeroponic farming is carried out in air medium, i.e., no soil is used. The nutrients are delivered to the roots by means of water droplets which are generated by sprayers or mist generators [5]. The water can then be recirculated so that it is highly efficient in water usage. There is an ample amount of oxygen available for the roots to take in the aeroponic system. However, due to its medium, aeroponics are prone to drying out [6].

In order to successfully implement an aeroponic farming system, a precise control system is required [7]. The control system typically employs a microcontroller as its central processing unit, some sensors, actuators, and communication chips. Several groups have reported implementation of electronic control systems for farming, including aeroponic farming. Internet of things (IoT) sensors were implemented in conventional farming to improve efficiency and time to harvest [8], [9]. An attempt to automate hydroponic farming was also reported [10]. For an aeroponic system, a successful local monitoring for temperature, humidity, and pH in potato production was reported [11]. Kuncoro *et al.* [12] reported an increase in potato production by implementing local monitoring and conditioning of the root chamber temperature. Some others reported on the online monitoring of aeroponic system [13]–[16].

These previous works, however, only touched a few or some aspects of robust aeroponic farming. Reports were limited to the monitoring of farming parameters, the control of the actuators, the use of artificial light, or network interconnectivity. This work attempted to achieve: i) Automated monitoring and control of aeroponic farming parameters, ii) Indoor robustness through an artificial lighting system, and iii) Remote access through IoT connectivity. The successful integration of these aspects is detrimental in realizing a more robust food production system in improving food security.

In the next section, a brief introduction to the key parameters for aeroponic farming is provided. It is followed by an explanation about the design method for the aeroponic system developed in this work which includes the design of water and nutrient distribution system, the temperature control system, and the lighting system. The data obtained from the system were then analyzed in the results and discussions. Key findings were finally summarized in the conclusions.

2. RESEARCH METHOD

2.1. Key aeroponic parameters

Water, nutrients, light, and ambient temperature/climate are some of the most important parameters in any farming methods. This applies to aeroponic farming as well, with some adaptation due to the aeroponic characteristic of using air as the only aggregate. The use of air also infers that drying-out is the most serious and frequent problem so that an important emphasis is required to water and ambient temperature management [6].

Water is one of the most important intakes for plants and it is collected by the roots. Efforts have been made to improve the control for water supply of the conventional farming system by implementing IoT and automation technologies [17], [18]. It is important to note that in conventional and hydroponic farming, the roots have direct access to water since they are placed in soil, water, or other aggregates containing an adequate amount of water or humidity. In contrast, the roots in the aeroponic system do not have direct access to water since they are hung in the air. This has put plants in the aeroponic system to be prone of drying-out [6]. Important nutrients are also delivered through water intake. Therefore, a reliable control system to supply water and monitor the humidity of the root chamber is impeccable in the aeroponic system.

The collected water and nutrients are then converted into chemical energy by the photosynthesis process. This correlates directly to the availability of light. The availability of light in the wavelength of 400-700 nm allows photosynthesis and these are known as photosynthetically active radiation (PAR) [19]. Aside from photosynthesis, plants respond differently to different kinds of light spectrum [20]. In a shade or a light-lacking environment, plants grow longer in order to obtain better light exposure. It was shown that specific processes in plants were triggered by specific light spectrum, i.e., far red, red, blue, and green light. The far red-and-red-light triggers phytochromes, the blue light triggers cryptochrome, while the green light triggers cryptochromes and phototropins. These photoreceptors are responsible for various plant morphology such as stem elongation, leaf expansion, and flowering. The overall spectrum around 280-800 nm is known as photo-biologically active radiation (PBAR) [19].

The chemical process in plants is also highly affected by the ambient temperature [1]: on the ground and underground. In conventional soil farming, the underground temperature depends on the location and elevation of the area. The aeroponic farming system allows control of the root temperature, independent of the location and elevation of the area. This can be achieved by modifying the air of the root chamber through the use of actuators such as fan [6] and external refrigeration [12]. It is reported that the temperature for the root chamber should not exceed 30 °C [1].

Additionally, having the roots hanging in air increases oxygen supply for plants grown by aeroponic farming. Direct access to the air guarantees an ample amount of oxygen for the roots. It also prevents the occurrence of disease due to exposure to moist and stagnant aggregates or medium. This combination supports better nutrition assimilation for the plant and promotes faster development.

2.2. System design

The system was designed to perform automated monitoring and control of an aeroponic system which accommodates six water spinach plants (*Ipomea reptans*). The system monitors and controls 3 parameters: water and nutrient distribution, temperature, and light. This was carried out by employing specific sensors and actuators as shown in Figure 1. Wemos D1 mini were used as the main processor as well as the communication chip. Data and information were distributed through a wireless connection and were displayed on the ThingSpeak website.

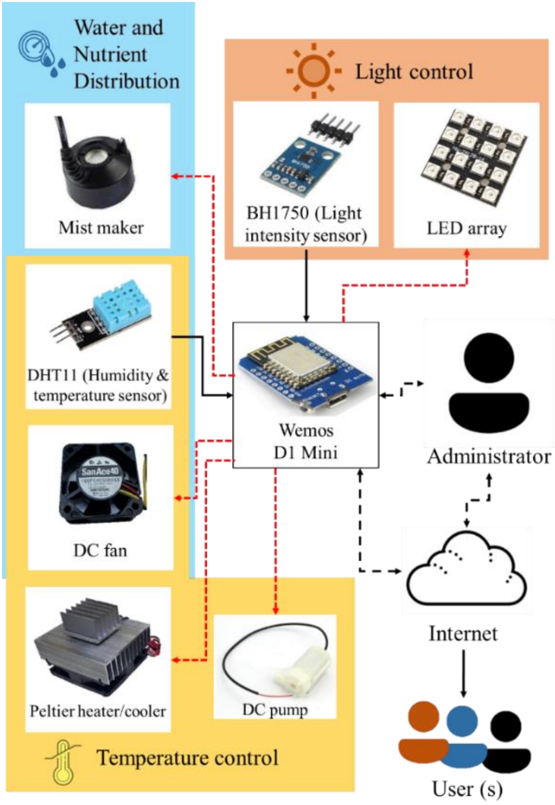

Figure 1. Overview of system design, the parameters, and components

This aeroponic system has 2 chambers: the root and the shoot chamber as shown in Figure 2. The root chamber simulated the condition of the soil or aggregates for the roots and hence it was designed to be dark. The root chamber held an impraboard platform where the plants were hung on to. Electronic sensors and actuators for the distribution of nutrient-rich water and for the monitoring and control of ambient temperature were also housed in the root chamber. The shoot chamber provides the space for the stem and leaves. It allows light irradiation (sunlight as well as light emitting diodes or LED) and a free flow of air. The processor, light sensor, and LED were placed in the vicinity of the shoot chamber.

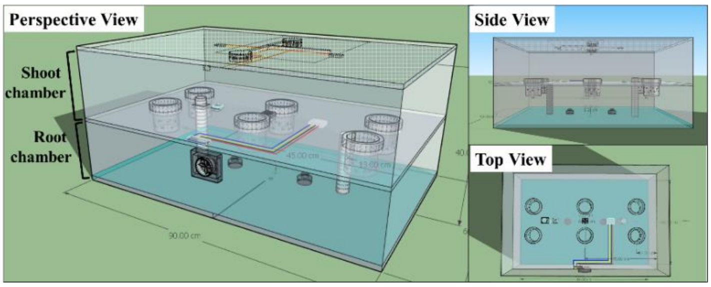

Figure 2. System physical design and placement of component

2.3. Water and nutrient distribution system

The water in aeroponic farming serves as hydration media as well as the source of nutrients. Nutrient-rich water is placed in the root chamber without directly touching the roots. In this work a temperature and humidity sensor (DHT11), two mist makers, and a DC fan were employed to construct the water and nutrient distribution system. Water was delivered in the form of mist generated by ultrasonic mist makers. The micron droplet size allows better nutrient absorption [5]. The DC fan was used to improve the mist distribution in the root chamber.

DHT11 was implemented to monitor the temperature and humidity of the root chamber. This sensor is capable of measuring temperature and humidity levels from 0 to 50 °C and from 20% to 90%, respectively. In the implementation, the sensor module was validated by using a commercial temperature and humidity sensing device. The DHT11 module was connected to Wemos D1 mini so that all measured data can be wirelessly transmitted through the network and displayed on the website.

Two ultrasonic mist makers were used to generate droplets of nutrient-rich-water in the form of mist. A 24 V mist maker was used and it is expected to produce 5 to 6 μm droplet [21]. The mist generated was rather heavy and occupied only the lower part of the root chamber. Therefore, a 5 V DC fan was installed to better distribute the mist and hence improve the overall humidity of the root chamber. The set of actuators (mist makers and fan) was programmed to turn on for 5 minutes and off for the same duration (50% duty cycle).

2.4. Temperature control system

The temperature in the root chamber was also monitored by the DHT11 sensor. The temperature data was taken every minute and transmitted to ThingSpeak website. For optimal growth of *Ipomea reptans*, the root chamber temperature is required to be between 25 and 30 °C.

It was understood that the ambient temperature in the area of experiment tended to go well above the target temperature. The use of ultrasonic mist maker is also known to generate heat in the process. Therefore, the temperature control system was geared towards reducing the heat in the root chamber. The actuators for temperature control consist of a Peltier cooler, a 5 V DC pump, and a 5 V DC fan. A water block was attached to the cold metal sink of the Peltier cooler to improve the heat removal from water to the Peltier cooler. The set of Peltier cooler and pump were programmed to turn on and off if the temperature of the root chamber went over 29.0 °C and went below 25.0 °C, respectively.

2.5. Lighting system

Light intensity sensor BH1750 was used to collect light intensity data throughout the experiment. Arrays of LEDs were used as an artificial light assisting the growth of plants in the aeroponic system. The sensor measures artificial light (LEDs) as well as the natural one (the sunlight).

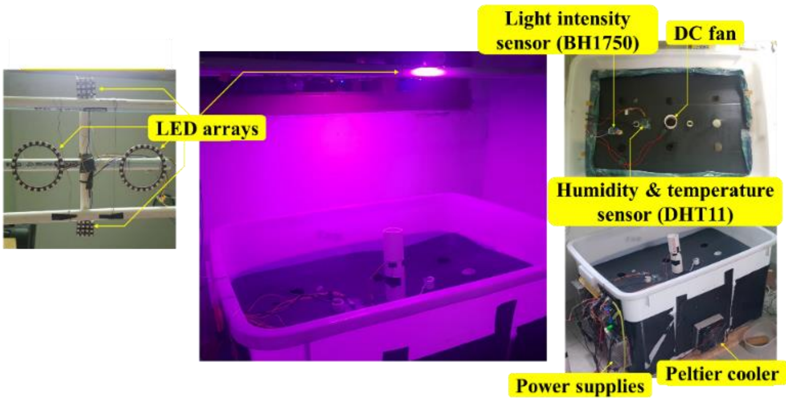

Figure 3. Results of system implementation

Two sets of 4x4 RGB LED array and two sets of Neopixel RGB LED ring were set 30 cm above the shoot chamber. In total, the LED takes ~7.2 W through its 80 LED chips. LED is beneficial for agriculture applications because of several characteristics: minimum heat irradiation, long lifetime, dimmable, and color selective (monochromatic) [22], [23]. The RGB LEDs were programmed to produce blue and red lights. Red light is effective in triggering photosynthesis while blue light is important in forming chlorophyll and performing photomorphogenesis [24], [25]. The aeroponic system is as shown in Figure 3.

3. RESULTS AND DISCUSSION

3.1 Temperature and humidity monitoring and control

The root chamber's temperature baseline was determined by measuring the temperature without activating the Peltier heater/cooler. A typical result is shown in the gray-square of Figure 4(a). The maximum, minimum, and average temperatures were 33.7, 28.6, and 31.2 °C, respectively. The duration in which the temperature rose above 30 °C was 84.5% in a day. This result is unsatisfactory for plant growth because the temperature exceeded 30 °C. After turning on all the actuators for temperature control, the temperature shifted down towards the ideal temperature for plant growth. The maximum, minimum, and average temperatures were 30.5, 27.5, and 28.8 °C, respectively. The duration of the temperature being above 30 °C was reduced to 7.3% in a day.

The data indicates that the monitoring and control system is effective in maintaining the temperature required for plant growth, i.e., the *Ipomea reptans.* The simple if-then-else control system was sufficient to overcome the temperature deviation occurred in the vicinity of the experiment area. A more comprehensive perspective of the temperature condition is shown in Figure 4(b). It was evident that the aeroponic system was capable of monitoring and controlling the temperature well within the ideal range for the whole growth period of *Ipomea reptans*.

The results of humidity monitoring and control system are shown in Figure 5. The humidity without any intervention is shown as gray-square. The blue-filled-circle indicates the humidity with active actuators. From this typical daily humidity data, it can be seen that the humidity was well kept at ~95%. It is noted that this value is at the maximum reading of DHT11 so this data can also be interpreted as having a near saturated humidity. There was no dry-out problem during the growth period so that the 5 minutes on and off cycle (50% duty cycle) is effective to maintain the humidity of the aeroponic system.

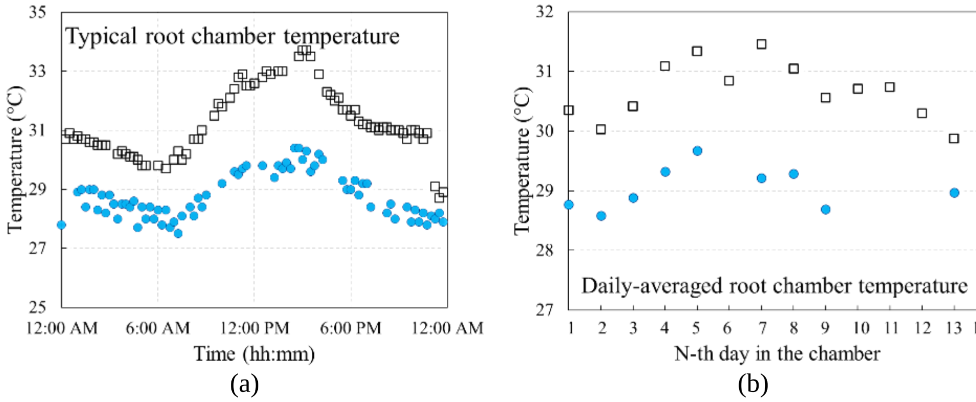

Figure 4. The result of chamber temperature monitoring: (a) A typical temperature variation in a day and (b) the average daily temperature variation during the whole growing period; the gray-square shows the baseline temperature without actuators while the blue-filled-circle shows temperature with active actuators

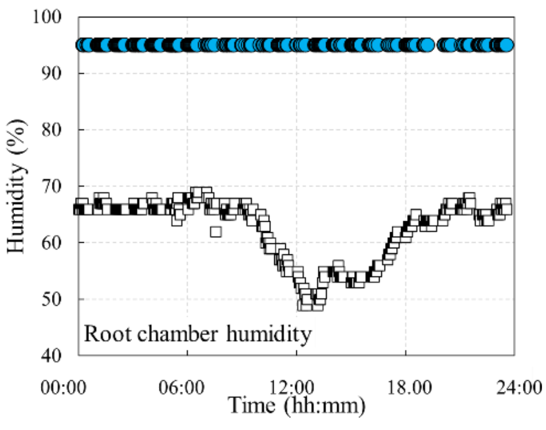

Figure 5. The gray-square shows the baseline humidity without actuators while blue-filled-circle shows humidity with active actuators

3.2. Light intensity monitoring and control

The aeroponic system was placed indoor under a diffuser in Jakarta, Indonesia. The light intensity data is shown in Figure 6. The black-square indicates the light intensity measurement from natural sunlight (without any LED being turned on) while the yellow-circle indicates the light intensity measurement from both natural sunlight and LED. It can be inferred from the graph that sunlight impinges on the aeroponic system from around 6 am to 6 pm which is consistent with solar radiation characteristics of the tropical climate.

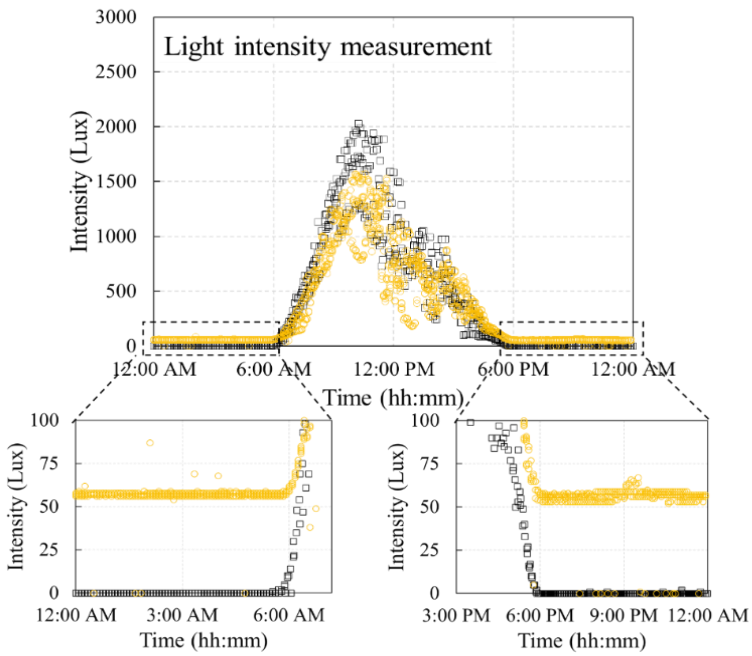

Figure 6. The black-square shows the baseline light intensity from natural sunlight without LED assistance while the yellow-circle shows the light intensity of both natural sunlight and active LED

When the red and blue LEDs were activated, there was no significant difference that can be observed during the sunlight period. The effects of LED were visible before 6 am and after 6 pm with an intensity increase of around 50 lux. The effects of the LED on the plant's growth are discussed in the following section.

3.3. Effects of LED on the plant growth

Figure 7 shows the plant's growth in 2 lighting conditions, i.e., sunlight with and without LED assistance as indicated by yellowcircle and green-triangle, respectively. The plant's length is shown in Figure 7(a) while plant's leaf count is shown in Figure 7(b). Based on the plant's length and leaf count data without LED assistance, it can be seen that etiolation occurred. Etiolation is stem elongation in plants which occurs due to lack of light in general and specifically red light [23]. This means that the optical diffuser limited the sunlight arriving in the shoot chamber. In etiolation, the plant tried to find a better light source by elongating the stem without generating leaves.

Based on the plant's length and leaf count data with LED assistance, it can be seen that there were significant improvements in both parameters. Etiolated condition has made it easier to understand the significance of LED for the plants. Through interactions with phytochromes and cryptochromes, light induces reactions in plants such as seed germination, leaf expansion, directional growth, seedling de-etiolation, and stem elongation [26]. Phytochromes and cryptochromes are the plant's photoreceptors: they sense incoming light and react chemically. It was also reported that the red and blue light regulates de-etiolation in plants through the phytochrome phyB and cryptochrome cry1, respectively, [26], [27]. De-etiolation is a morphophysiological process in plants covering the shoot growth suppression, the apical hook opening, the emergence of leaves, and the photosynthetic apparatus formation [28]. This is consistent with current results in which the LED assistance resulted in a significant increase of the number of leaves.

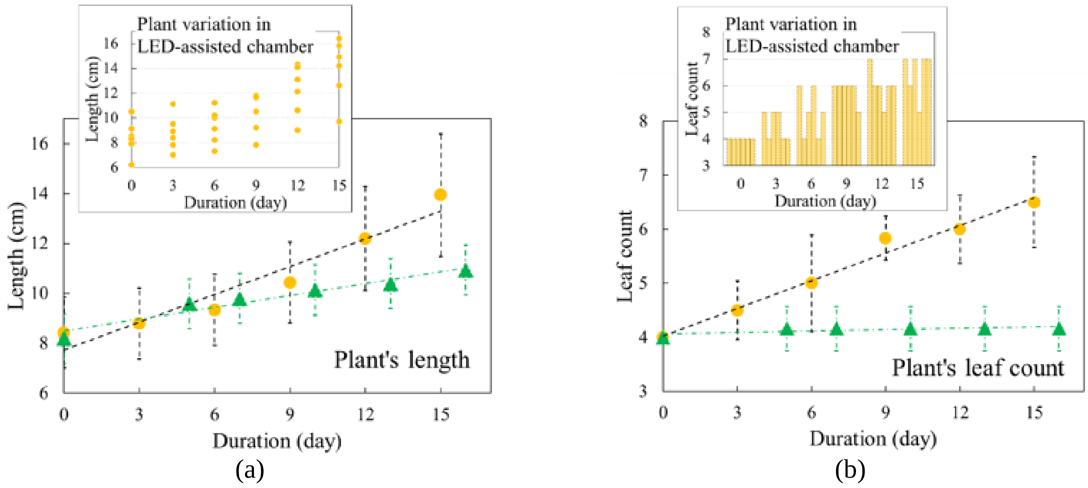

Figure 7. The plant growth effects of the LED as evaluated by (a) the plant's length and (b) the plant's leaf count with and without the LED assistance. The yellow-filled-circle and green-filled-triangle shows the plant's data with and without LED assistance, respectively

4. CONCLUSION

Design and implementation of an IoT based automated monitoring for an LED-assisted aeroponic system has been successfully carried out. The system achieved real time and online monitoring for temperature, humidity, and light intensity. IoT interconnectivity was established by employing Wemos D1 mini and the ThingSpeak platform. The system was also capable of online control for actuators of temperature, humidity, and light. The temperature was successfully maintained in the ideal temperature range of <30 °C with a typical average temperature of 28.8 °C. The humidity of the root chamber was also maintained such that no drying-out occurred. Data from light intensity monitoring and control indicated that the LED assistance was significant in improving the growth quality of *Ipomea reptans*. The system, data, and analysis in this work showed a feasible approach to a robust indoor aeroponic farming practice. It can be used as a base for further endeavor in realizing global food security.

ACKNOWLEDGEMENTS

This work was supported by Universitas Pertamina and Universitas Internasional Semen Indonesia collaborative research fund. Authors appreciate Azmi Alvian Gabriel of Universitas Internasional Semen Indonesia for valuable discussions on plant biology and farming aspects.

REFERENCES

[1] I. A. Lakhiar, J. Gao, T. N. Syed, F. A. Chandio, and N. A. Buttar, "Modern plant cultivation technologies in agriculture under controlled environment: a review on aeroponics," *Journal of Plant Interactions*, vol. 13, no. 1, pp. 338–352, Jan. 2018, doi: 10.1080/17429145.2018.1472308.

[2] FAO, IFAD, UNICEF, WFP, and WHO, "The state of food security and nutrition in the world 2021. transforming food systems for food security, improved nutrition and affordable healthy diets for all," Food and Agriculture Organization, Rome, 2021, doi: 10.4060/cb4474en.

[3] J. M. Clawson, A. Hoehn, L. S. Stodieck, P. Todd, and R. J. Stoner, "Re-examining aeroponics for spaceflight plant growth," Jul. 2000, doi: 10.4271/2000-01-2507.

[4] I. A. Lakhiar *et al.*, "Overview of the aeroponic agriculture – An emerging technology for global food security," *International Journal of Agricultural and Biological Engineering*, vol. 13, no. 1, pp. 1–10, 2020, doi: 10.25165/j.ijabe.20201301.5156.

[5] M. H. Tunio *et al.*, "Influence of atomization nozzles and spraying intervals on growth, biomass yield, and nutrient uptake of butter-head lettuce under aeroponics system," *Agronomy*, vol. 11, no. 1, Jan. 2021, doi: 10.3390/agronomy11010097.

[6] I. A. Lakhiar, G. Jianmin, T. N. Syed, F. A. Chandio, N. A. Buttar, and W. A. Qureshi, "Monitoring and control systems in agriculture using intelligent sensor techniques: A review of the aeroponic system," *Journal of Sensors*, vol. 2018, pp. 1–18, Dec. 2018, doi: 10.1155/2018/8672769.

[7] M. Pala, L. Mizenko, M. Mach, and T. Reed, "Aeroponic greenhouse as an autonomous system using intelligent space for agriculture robotics," in *Robot Intelligence Technology and Applications 2*, Springer, 2014, pp. 83–93.

[8] P. Tangwannawit and K. Saengkrajang, "An Internet of things secosystem for planting of coriander (Coriandrum sativum L.)," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 5, pp. 4568–4576, Oct. 2021, doi: 10.11591/ijece.v11i5.pp4568-4576.

[9] S. T. Emmanuel, C.O.A. Awosope, and E. O. Diagi, "Microcontroller-based vertical farming automation system," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 4, pp. 2046–2053, Aug. 2018, doi:

10.11591/ijece.v8i4.pp2046-2053.
[10] R. Lakshmanan, M. Djama, S. Perumal, and R. Abdulla, "Automated smart hydroponics system using Internet of things," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 6, pp. 6389–6398, Dec. 2020, doi: 10.11591/ijece.v10i6.pp6389-6398.
[11] I. Idris and Muhammad Ikhsan Sani, "Monitoring and control of aeroponic growing system for potato production," in *2012 IEEE Conference on Control, Systems & Industrial Informatics*, Sep. 2012, pp. 120–125, doi: 10.1109/CCSII.2012.6470485.
[12] C. B. D. Kuncoro, T. Sutandi, C. Adristi, and Y.-D. Kuan, "Aeroponics root chamber temperature conditioning design for smart mini-tuber potato seed cultivation," *Sustainability*, vol. 13, no. 9, May 2021, doi: 10.3390/su13095140.
[13] F. Francis, P. L. Vishnu, M. Jha, and B. Rajaram, "IoT-based automated aeroponics system," in *Intelligent Embedded Systems*, Springer, 2018, pp. 337–345.
[14] M. I. Sani, S. Siregar, A. P. Kumiawan, R. Jauhari, and C. N. Mandalahi, "Web-based monitoring and control system for aeroponics growing chamber," in *2016 International Conference on Control, Electronics, Renewable Energy and Communications (ICCEREC)*, Sep. 2016, pp. 162–168, doi: 10.1109/ICCEREC.2016.7814977.
[15] F. Rahman, I. J. Ritun, M. R. Ahmed Biplob, N. Farhin, and J. Uddin, "Automated aeroponics system for indoor farming using arduino," in *2018 Joint 7th International Conference on Informatics, Electronics & Vision (ICIEV) and 2018 2nd International Conference on Imaging, Vision & Pattern Recognition (icIVPR)*, Jun. 2018, pp. 137–141, doi: 10.1109/ICIEV.2018.8641026.
[16] C. A. Jamhari, W. K. Wibowo, A. R. Annisa, and T. M. Roffi, "Design and implementation of IoT system for aeroponic chamber temperature monitoring," in *2020 Third International Conference on Vocational Education and Electrical Engineering (ICVEE)*, Oct. 2020, pp. 1–4, doi: 10.1109/ICVEE50212.2020.9243213.
[17] A. Deroussi *et al.*, "A novel autonomous remote system applied in agriculture using transmission control protocol," *International Journal of Reconfigurable and Embedded Systems (IJRES)*, vol. 11, no. 1, pp. 1–12, Mar. 2022, doi: 10.11591/ijres.v11.i1.pp1-12.
[18] A. I. Badran and M. Y. Kashmoola, "Electronic control of water resources using smart field irrigation systems," *International Journal of Informatics and Communication Technology (IJ-ICT)*, vol. 10, no. 2, pp. 116–125, Aug. 2021, doi: 10.11591/ijict.v10i2.pp116-125.
[19] S. Bures, M. Urrestarazu Gavilán, and S. Kotiranta, "Artificial lighting in agriculture," *SPE3 Especialistes en serveis per la producció editorial*, 2018.
[20] R. Sellaro *et al.*, "Cryptochrome as a sensor of the blue/green ratio of natural radiation in Arabidopsis," *Plant Physiology*, vol. 154, no. 1, pp. 401–409, Sep. 2010, doi: 10.1104/pp.110.160820.
[21] S. Kooij, A. Astefanei, G. L. Corthals, and D. Bonn, "Size distributions of droplets produced by ultrasonic nebulizers," *Scientific Reports*, vol. 9, no. 1, Dec. 2019, doi: 10.1038/s41598-019-42599-8.
[22] R. C. Morrow, "LED lighting in horticulture," *HortScience*, vol. 43, no. 7, pp. 1947–1950, Dec. 2008, doi: 10.21273/HORTSCI.43.7.1947.
[23] N. Yeh and J.-P. Chung, "High-brightness LEDs—energy efficient lighting sources and their potential in indoor plant cultivation," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 8, pp. 2175–2180, Oct. 2009, doi: 10.1016/j.rser.2009.01.027.
[24] G. D. Massa, H.-H. Kim, R. M. Wheeler, and C. A. Mitchell, "Plant productivity in response to LED lighting," *HortScience*, vol. 43, no. 7, pp. 1951–1956, Dec. 2008, doi: 10.21273/HORTSCI.43.7.1951.
[25] J. Heo, C. Lee, D. Chakrabarty, and K. Paek, "Growth responses of marigold and salvia bedding plants as affected by monochromic or mixture radiation provided by a light-emitting diode (LED)," *Plant Growth Regulation*, vol. 38, no. 3, pp. 225–230, 2002, doi: 10.1023/A:1021523832488.
[26] P. Lymperopoulos, J. Msanne, and R. Rabara, "Phytochrome and phytohormones: working in tandem for plant growth and development," *Frontiers in Plant Science*, vol. 9, p. 1037, Jul. 2018, doi: 10.3389/fpls.2018.01037.
[27] M. de Wit, V. C. Galvão, and C. Fankhauser, "Light-mediated hormonal regulation of plant growth and development," *Annual Review of Plant Biology*, vol. 67, no. 1, pp. 513–537, Apr. 2016, doi: 10.1146/annurev-arplant-043015-112252.
[28] V. V Kusnetsov, A. S. Doroshenko, N. V Kudryakova, and M. N. Danilova, "Role of phytohormones and light in de-etiolation," *Russian Journal of Plant Physiology*, vol. 67, no. 6, pp. 971–984, Nov. 2020, doi: 10.1134/S1021443720060102.

BIOGRAPHIES OF AUTHORS

Teuku Muhammad Roffi received the B.Eng. degree in electrical engineering from Institut Teknologi Bandung, Indonesia. He was awarded the Monbusho (MEXT) scholarship from the Japanese Government and completed the M. Eng. and Ph.D. degrees in electronic engineering from The University of Electro-Communications, Japan in 2013 and 2016, respectively. He then joined Toyota Technological Institute with a postdoctoral fellowship in 2017. He is currently an Assistant Professor at the Department of Electrical Engineering, Universitas Pertamina, Indonesia. His research interests include electronic materials, electronic devices, and electronics for internet of things (IoT) as well as smart systems. He can be reached at email: teuku.roffi@universitaspertamina.ac.id or roffi@ieee.org.

Charisma Aulia Jamhari holds a B.Eng. degree in electrical engineering from Universitas Pertamina, Indonesia. He is currently an engineer with PT. Kotaminyak Internusa, Indonesia. His areas of interest are automation, internet of things (IoT), and energy management. He can be contacted at email: charismajam@gmail.com. See his profile on https://www.linkedin.com/in/charismaul.