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Embedded System for Controlling Plant Lighting in Vapourponics Farming

Abstract: - Plants need light to grow. Lighting systems are necessary for plant research. Recent advances in light-emitting diode (LED) technology allow for several plant light response studies. LED benefits include solidity, lifespan, small element volume, radiant flux controllability, and monochromaticity. A lighting system must produce precisely controlled light spectra to trigger a variety of plant responses for plant light response research. Computers and graphical user interface programs may regulate the PFD and mixing ratios of four wavelength-band lights in the plant lighting system. A highly uniform PFD distribution was attained even with an intentionally skewed PFD gradient. This study investigates a plant illumination system with four wavelength-band LEDs for indoor plant growing. LED technology can precisely manage light spectrum and intensity, and the research explores how different light wavelengths affect plant growth and development. The article also discusses LED lighting's energy efficiency and heat reduction benefits. According to studies, a plant illumination system with four wavelength-band LEDs can boost plant growth and yield in indoor gardening and hydroponics. An autonomous plant lighting system with four wavelength-band LEDs can manage light intensity, spectrum, and timing for optimal plant growth and development. Sensors change LED lighting based on plant development stage and ambient light conditions. Choose from four wavelength-band LEDs to get the best light spectrum for your plant. A microprocessor or other control system can vary LED intensity and proportions to control photon flux density and mixing ratio. For different plant growth stages, the autonomous system can imitate natural daylight cycles and give the right spectrum and intensity of light. This can boost plant growth and production while saving energy and heat. Indoor gardening and hydroponics, where natural light is scarce, benefit from an autonomous plant lighting system with four wavelength-band LEDs. This technique can also help grow plants in small spaces or poor environments.

Keywords: LEDs; Light adjustment; Photon flux; Sensors; Vapourponic farming

I. INTRODUCTION

Vapourponics farming is a cutting-edge strategy in the fast-growing field of agricultural technology that avoids traditional soil-based production. Vapourponics, a technique that suspends plant roots in a mist containing abundant nutrients, enhances nutrient absorption and speeds up growth rates. This method holds the potential to revolutionize sustainable agriculture. Nevertheless, the careful regulation of environmental variables, especially sunlight, is crucial for optimizing plant well-being and productivity. The development of an embedded system for regulating plant lighting is essential in this context. This technology has the potential to revolutionize vapourponics by incorporating innovative sensors, real-time data processing, and automated light modifications. It ensures that plants receive the ideal amount of light exposure by adjusting the spectral characteristics to their unique demands and reacting to changing growing conditions. The combination of electronics, horticulture, and data science in this research work is a technological advancement and a crucial step towards improving food security in unpredictable climate conditions. The use of light-emitting diodes (LEDs) technology in plant lighting systems allows for greater control over the light spectrum and intensity [1], which can be adjusted to meet the specific needs of different plants at different stages of growth. LED lighting systems are also energy-efficient, long-lasting, and can be designed to emit minimal heat, which reduces the risk of damage to plants [2]. Overall, a plant lighting system with four wavelength-band light-emitting diodes can be a valuable tool for indoor gardening, hydroponics, and other forms of plant cultivation. With careful selection of the LED spectrum and intensity, it is possible to achieve optimal plant growth and development, even in environments where natural light is not available or sufficient.

A plant lighting system with four wavelength-band light-emitting diodes LEDs can provide a range of light wavelengths that are essential for photosynthesis and plant growth. The four wavelength-band LEDs can be selected to provide the optimal light spectrum for the specific plant being grown. Blue light (400-500 nm) is essential for plants' vegetative growth and can help regulate plant growth and development. Red light (600-700 nm) is important for flowering and fruiting and can enhance the yield and quality of crops. Green light (500-600 nm) is not as useful for photosynthesis but can contribute to plant growth and development. Far-red light (700-800 nm) is important for regulating plant growth and can help to promote seed germination. UV light (280-400 nm) can stimulate secondary metabolite production and enhance certain plants' nutritional quality.

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Plants require light for photosynthesis, which is directly received through sunlight, which has a full spectrum of both visible and invisible wavelengths to make a replica of the wavelength high-intensity discharge lamps were used in the hydroponics system, which helps grow plants the way sunlight did but the power consumed by high-intensity discharge lamp was making the whole system costly, to reduce the cost LED-based lights were used as it consumed less power and emitted less heat as well bringing the overall cost of using artificial light down [3]. Plants, when grow, do not require all the wavelengths of light; thus, a device was developed that had a grow light using LEDs but of only two colors: red and blue. These wavelengths are most useful for the plant's growth [4]. The LED grow light device improved grow light, which can be further used in dot grow plants by replacing high intensity grow lights and reducing the cost by cutting down the power used. The system comprises a fitting that holds a set of red and blue LEDs mounted or soldered on a circuit board and is powered by a supply board. The placement of red and blue LED is designed in a way that it boosts the growth of plants as the LEDs are used for twenty-four hours the heat can destroy the board thus to improve the grow lights working a heat sink is mounted on the circuit board which has a heat sink paste between the joint of the two so that heat can evenly distribute and removed to keep the circuit working for fast transfer of heat a fan is mounted on the heat sink to circulate the heat outside the fittings [5]. The distance between the plants and light is mounted in a way that the growth of plant is maximum while the LEDs are controlled using a controller to command at what time which LED should glow. The plants can not solely grow on blue and red light it requires other wavelengths as well which are blue red and pink light by increasing just one wavelength the growth and yield of crops show a significant difference thus decreasing the time taken by the crop to grow [6].

This study aims to create and execute a specialized embedded system for vapourponics farming that utilizes the benefits of LED technology. The device would adaptively regulate light intensity and spectral output based on real-time data on plant growth circumstances by combining a multi-wavelength LED array with sophisticated control algorithms. By accurately managing the light conditions, the system can maximize energy efficiency, minimize operational expenses, and improve the nutritional value of crops. This investigation intends to improve the vapourponics field and contribute to the broader goal of establishing sustainable agriculture in an era of climate change and resource scarcity. With this endeavor, we aim to establish a novel benchmark in controlled-environment agriculture, thereby facilitating the development of more robust and effective food production systems.

II. MATERIALS AND METHODS

The plant requires sunlight to grow, but in our system, we are providing plants artificial grow lights that can mimic all the phases of a day, like morning, afternoon, evening, and night that are controlled with the help of a microcontroller making a healthy environment around plants for better growth [5, 7, 8]. Smart LED grow light setup mimics natural lighting conditions like morning, afternoon, evening, and night while consuming less power, thus providing an environment for plants to grow just as they grow in natural sunlight [9].

The lights are LED lights, thus consuming very little power to glow for a whole day, making the whole system economical and profitable. The ratio in which the LED lights are used is as follows:

Morning: In the morning, blue and red LED strips are automatically turned ON with the help of a microcontroller and Real Time Clock to increase the vegetation. (B: R=2:3 to 3:4)

Afternoon: In the afternoon, violet light LED along with Blue and Red LEDs is used to enhance the taste and color of the crops. (V: B: R=2:3:4 to 4:4:4)

Evening: In the evening, far red is used, which speeds up phytochrome conversion and helps the plants change from day to night. This change of the state in plants is an essential part of their growth as it is responsible for switching to respiration mode from photosynthesis mode for the proper exchange of gases. (B: R: Fr=4:4:2 to 3:3:4)

Night: In the night, blue and red LEDs are activated, which goes dim for the plants to do respiration and provide energy to the cells. (B: R=3:3 to 1:1)

A plant lighting system with four wavelength-band LEDs providing photon flux density and mixing ratio control can be designed and implemented using the following steps:

(i) Determine the desired wavelengths: Plants require different wavelengths of light for optimal growth and development. The four most important wavelengths for plant growth are violet (380 – 450 nm; at 660 – 770 Hz), blue (450 – 500 nm; at 600 – 660 Hz), red (650 – 700 nm; at 450 – 490 Hz), and far-red (700 - 750 nm; at 400 – 450 Hz). Choose LEDs that emit light in these wavelength ranges.

(ii) Select LEDs with appropriate photon flux density: The photon flux density (PFD) is the number of photons per unit area per unit time. Different plants require different levels of PFD for optimal growth. Choose LEDs with appropriate PFD values for the plants being grown.

(iii) Determine the desired mixing ratio: The mixing ratio of different light wavelengths can significantly impact plant growth. For example, blue light is important for vegetative growth, while red light is important for flowering. Determine the desired mixing ratio of the four wavelengths of light.

(iv) Design the LED array: Use the selected LEDs to design an array that provides the desired PFD and mixing ratio. This can be done using software tools that simulate the light distribution and optimize the layout of the LEDs.

(v) Implement the LED array: Build the LED array and integrate it into the plant growth system. Use sensors to measure the PFD and adjust the mixing ratio as necessary to achieve optimal plant growth.

(vi) Monitor and maintain the system: Regularly monitor the PFD and mixing ratio to ensure the plants receive the correct amount and type of light. Replace any faulty LEDs and perform routine maintenance as needed.

Following these steps, a plant lighting system with four wavelength-band LEDs providing photon flux density and mixing ratio control can be designed and implemented for optimal plant growth and development.

III. DEVELOPMENT

Building an automatic plant lighting system with four wavelength-band LEDs requires several hardware components and software tools [10]. Here are the major steps to build such a system:

Hardware Components:

1. Microcontroller board (e.g., Arduino, Raspberry Pi)
2. LED driver board
3. Four different wavelength-band LEDs (e.g., Blue, Violet, Red and Far Red)
4. Sensor module (e.g., light sensor, temperature and humidity sensor, moisture sensor)
5. Power supply (e.g., AC/DC adapter or battery)
6. LED array (e.g., strip or panel)
7. Resistors, capacitors, wires, and breadboard or PCB for prototyping.

Software Tools:

1. Arduino Integrated Development Environment (IDE) or Python programming language
2. LED control library (e.g., FastLED library for Arduino)
3. Sensor data acquisition library (e.g., DHT library for temperature and humidity sensor)
4. Serial communication library (e.g., PySerial for Python)
5. User interface libraries (e.g., Tkinter for Python, LCD displays, or mobile app).

Step-by-Step Process:

1. Design the schematic diagram of the system and identify the pin connections and interfaces for the hardware components.
2. Prototype the circuit on a breadboard or PCB, connect the components, and test the basic functions such as LED lighting, sensor data reading, and microcontroller programming.
3. Write the code for the microcontroller board using the Arduino IDE or Python programming language. The code should read the sensor data, calculate the LED spectrum and intensity based on the target growth stage, and control the LED driver to adjust the LED output.
4. Incorporate the LED control library and sensor data acquisition library in the code. These libraries provide functions to control the LED output and read the sensor data from the sensor module.
5. Implement a user interface to allow the user to select the target growth stage, adjust the LED spectrum and intensity, and view the sensor data and LED settings.
6. Set up the LED array and connect it to the LED driver board. The LED driver board should be able to output the appropriate current and voltage to each LED based on the microcontroller's commands.
7. Test the system and adjust the LED spectrum and intensity based on the sensor data and the desired growth stage. Monitor the plant growth and quality and record the sensor data and LED settings for further analysis.
8. Optimize the system performance by fine-tuning the LED spectrum and intensity, sensor placement, and watering and nutrient schedule.
9. Document the system design, hardware components, and software code, and share the project with the community through online forums or social media platforms.

Hence, building an automatic plant lighting system with four wavelength-band LEDs requires a combination of hardware and software skills and a deep understanding of plant growth and lighting requirements.

Overview of Algorithm

A combined lighting system, unlike direct sunlight, requires a separate emergency power system (with storage batteries and a suitable control system) and an additional artificial lighting source. Another problem may be the plants' negative reaction to changes in the light spectrum [11]. Daytime - sunlight after passing through concentrators, secondary reflectors, and light guides, night-time - artificial lighting. In general, systems that combine small vitamins and vegetable SGs are too expensive in terms of energy consumption. The volatility of solar flux over time and the demand for additional systems for receiving, concentrating, transporting, distributing, and storing solar energy make artificial light sources suitable for near-future space greenhouses [12]. Light sources based on LEDs are considered to be the most efficient and promising among SG's artificial light sources currently in development. High energy efficiency, safety, and durability are the decisive advantages of LEDs in plant lighting.

Here is a representation of an automatic plant lighting system with four wavelength-band light-emitting diodes (LEDs): [Sensor Module] - [Microcontroller] - [LED Driver] - [LED Array].

The system starts with a sensor module that measures ambient light levels and plant growth stage. The sensor module could include sensors such as a light sensor, temperature sensor, humidity sensor, and moisture sensor.

The data from the sensor module is then transmitted to the microcontroller, which processes the data and controls the LED driver. The microcontroller could be an Arduino board, Raspberry Pi, or any other microcontroller that can be programmed to control the LED driver based on the input from the sensor module.

The LED driver is responsible for regulating the current to the LED array, which consists of four wavelength-band LEDs selected to provide the optimal light spectrum for the specific plant being grown. The LED driver could be a constant-current driver or a pulse-width modulation (PWM) driver, which can provide the flexibility to adjust each LED's intensity and relative proportions [13].

The LED array emits light onto the plants, providing the necessary spectrum and intensity to support optimal plant growth and development. The LED array could be mounted on a fixture that can be adjusted in height and angle to optimize light distribution.

Therefore, one can say that an automatic plant lighting system with four wavelength-band LEDs and a microcontroller-based control system can provide precise control over light intensity, spectrum, and timing, resulting in optimal plant growth and development.

Embedded System Algorithm

Here is an embedded system algorithm for an automatic plant lighting system with four wavelength-band LEDs:

1. Initialize the system and set up the necessary hardware components, including the sensor module, microcontroller, LED driver, and LED array.
2. Configure the sensor module to measure ambient light levels, temperature, humidity, and moisture levels.
3. Set up the microcontroller to receive input from the sensor module and control the LED driver based on this input.
4. Define a set of rules for determining the appropriate LED spectrum and intensity based on the sensor data. For example, suppose the ambient light level is low and the plant is in the vegetative growth stage. In that case, the system should provide a blue-dominated spectrum with a relatively high intensity.
5. Program the microcontroller to calculate each LED's intensity and relative proportions needed to achieve the desired spectrum.
6. Set the LED driver to output the appropriate current to each LED based on the calculated intensity and proportions.
7. Repeat steps 4-6 at regular intervals and adjust the LED spectrum and intensity based on changes in the sensor data.
8. Monitor the sensor data and adjust the LED spectrum and intensity as needed to ensure optimal plant growth and development.
9. Turn off the LED array during periods of darkness to simulate natural daylight cycles.
10. Incorporate a user interface (e.g., LCD display or mobile app) to allow the user to view and adjust the system settings, such as the target growth stage and lighting schedule.
11. Implement a data logging feature to record the sensor data and LED settings over time, which can be used to analyze and optimize the system performance.

Using an embedded system design, this algorithm provides a more detailed and integrated approach for an automatic plant lighting system with four wavelength-band LEDs. It leverages the processing power of the microcontroller and incorporates advanced features such as user interface and data logging to provide a comprehensive and efficient system for indoor plant cultivation.

Wavelength Control System in LED(S) as Grow Lights for Different Stages of Plant Growth

1. Identify the plant species and the growth stage. Different plants have different lighting requirements, and the lighting needs also vary depending on the growth stage (e.g. germination, vegetative, flowering).
2. Determine the optimal spectrum of light for the plant species and growth stage. Research and scientific studies have shown that different wavelengths of light affect plant growth and development differently. For example, blue light promotes vegetative growth, red light enhances flowering and fruiting, and far-red light regulates plant elongation.
3. Choose the appropriate LED lights with the desired wavelength spectrum. LED grow lights come in various colors, including violet, blue, red and far-red. Some LED grow lights are designed to emit a specific wavelength range, while others offer a broad spectrum that can be adjusted according to the plant's needs [19].
4. Set up the LED lights in the plant growth area. The LED lights can be arranged in a specific pattern, depending on the plant's size, shape, and light requirements. The LED lights can be positioned closer or farther from the plants, depending on the intensity of light required.
5. Program the LED lights to turn on and off at specific intervals, depending on the plant's lighting needs. The lighting schedule may vary depending on the plant species and growth stage. For example, seedlings may require 16-18 hours of light per day, while mature plants may require 12-14 hours.
6. Monitor the plant growth and adjust the LED light spectrum and intensity as needed. Pay attention to the plant's response to the LED lights and make changes accordingly.
7. Record the LED light settings and plant growth data for future reference and analysis.

Overall, using different wavelengths of LED lights as grow lights for plants requires careful consideration of the plant species and growth stage and the optimal light spectrum and intensity required for each stage. By following this algorithm and adjusting the LED light settings as needed, you can create a tailored and efficient lighting system that promotes healthy plant growth and maximizes yields [20]..

Control System Description of a Plant Lighting System Along With a Graphical User Interface (GUI)

Input: Environmental sensors (e.g., temperature, humidity, CO_2), plant sensors (e.g., light intensity, soil moisture), and user inputs (e.g., desired lighting schedule, light intensity, spectrum) are collected and processed by the microcontroller.

Controller: The microcontroller processes the input signals and adjusts the LED lights accordingly. It sends signals to the LED drivers that regulate the current and voltage to the LEDs. The controller can also adjust the lighting schedule based on the user inputs and plant growth stage. The controller communicates with the GUI to display system status and user options.

LED Drivers: The LED drivers receive signals from the controller and regulate the current and voltage to the LEDs. This ensures that the LED lights emit the desired intensity and spectrum [14].

LED Light Array: The LED light array consists of four different wavelength-band LED lights that emit the desired spectrum of light for plant growth. The LED light array can be configured in various patterns to provide optimal coverage for the plants.

Plant Growth: The plants are exposed to the LED lights and absorb the light energy for photosynthesis and growth. The plant sensors provide feedback to the controller on the light intensity and other environmental factors affecting plant growth [15].

Output: The output signals from the plant and environmental sensors are sent back to the controller, which are processed and used to adjust the LED lights. The user can also receive output signals indicating the status of the system, such as the lighting schedule and intensity. The GUI displays system status, user options, and plant growth data.

Graphical User Interface (GUI): The GUI allows the user to interact with the plant lighting system. The user can set the lighting schedule, adjust the light intensity and spectrum, view system status and plant growth data, and receive alerts for system issues. The GUI communicates with the microcontroller to send and receive data, allowing the user to control the system remotely.

Real Time Clock module: In an automatic plant lighting system with a real-time clock that is designed to mimic sunlight throughout the day, the mixing ratio of photon flux density can be adjusted over time to match the changing spectral composition of natural sunlight.

To achieve this, the system can use a combination of sensors, such as light intensity sensors and temperature sensors, to monitor the environment around the plants and adjust the mixing ratio of the LED lights accordingly. The system can also incorporate a real-time clock that allows it to mimic the changing light conditions of the sun throughout the day. For example, during the morning hours, the system may use a higher proportion of blue and red LED light to mimic the natural blue light that plants receive during this time of day. As the day progresses, the system can gradually adjust the mixing ratio to include more red and far- red LED light, which mimics the warmer, redder light that plants receive in the late afternoon and evening.

The exact mixing ratio of photon flux density in an automatic plant lighting system with a real-time clock will depend on a variety of factors, including the specific plants being grown, the growth stage of the plants, and the desired growth outcomes. However, by using a combination of sensors and real-time clock control, it is possible to create a lighting system that provides the optimal spectral composition of light for plant growth and development throughout the day. Overall, the control system diagram of the plant lighting system and GUI show how the input signals are processed and used to regulate the LED lights, while the GUI provides an interface for user interaction and system monitoring. The system provides a tailored and efficient lighting schedule that promotes healthy plant growth and maximizes yields, while also allowing the user to control the system remotely and monitor plant growth data.

The code was developed using Python, and the RTClib library was used to get the current time from the Real Time Clock module and calculate the percentage of the day that has passed. It then uses a helper function to calculate the value for each wavelength based on the percentage of the day and sets the color of the RGB LED accordingly.

IV. RESULTS

The following graph, which mimics the sunlight through a daytime divided into four color bands, has been presented in Figure 1.

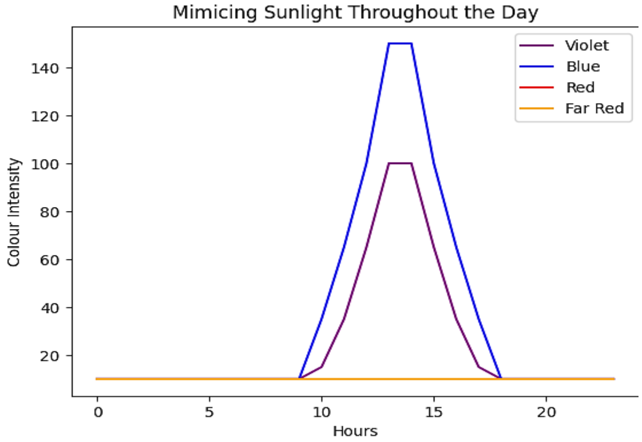

Fig. 1. Output from python compiler

Table 1 below shows the dataset for the relationship between various time stamps of the day and the ratio of different wavelengths of visible light.

Table I. Dataset indicating the relationship between various time stamps of the day and the ratio of different wavelengths of visible light

Hour (24-hour format)	Violet Value	Blue Value	Red Value	Far Red Value
00:00	0	0	0	0
01:00	0	0	0	0
02:00	0	0	0	0
03:00	0	0	0	0
04:00	0	0	0	0
05:00	0	0	0	0
06:00	20	30	10	5
07:00	30	50	30	15
08:00	50	80	60	30
09:00	60	100	70	35
10:00	70	120	80	40
11:00	80	140	90	45
12:00	90	150	100	50
13:00	80	140	90	45

14:00	70	120	80	40
15:00	60	100	70	35
16:00	50	80	60	30
17:00	30	50	30	15
18:00	20	30	10	5
19:00	0	0	0	0
20:00	0	0	0	0
21:00	0	0	0	0
22:00	0	0	0	0
23:00	0	0	0	0

Figure 2 depicts the relationship between various time stamps of the day and the different wavelengths of visible light.

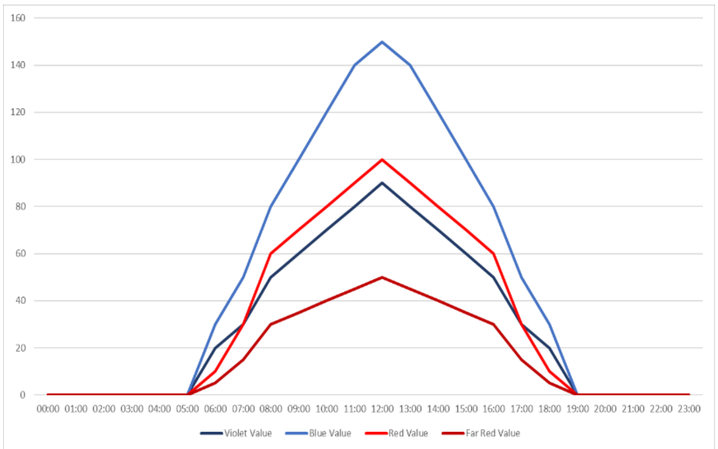

Fig. 2. Graph indicating the relationship between various time stamps of the day (x-axis) and the different wavelengths of visible light (y-axis)

The above code is designed to mimic sunlight throughout the day using an RGB LED and a Real Time Clock (RTC) module. The LED color changes throughout the day based on the current time and percentage of the day that has passed.

Here's a brief description of how the code works:

- The necessary libraries and pins for the RTC module and LED are defined at the beginning of the code.
- The setup () function initializes the RTC module and sets the LED pins as output.
- The loop () function continuously reads the current time from the RTC module and calculates the percentage of the day that has passed. This percentage is then used to determine the appropriate LED color.
- The LED color is determined by mapping the current time to a specific color value. The color spectrum shifts towards red in the morning and evening and towards blue in the middle of the day.
- The LED color is set using the analogWrite() function to adjust the brightness of the RGB LED red, green, and blue pins.
- The current time, percentage of the day that has passed, and LED color are printed on the serial monitor.

The result of running this code on an Arduino board with an RTC module and RGB LED would be a changing color of the LED throughout the day, with the color spectrum shifting towards red in the morning and evening and towards blue in the middle of the day. The exact color values and timing of the LED changes will depend on the specific values used in the code and the hardware setup of the LED and RTC module.

V. DISCUSSION AND CONCLUSIONS

This study has effectively created an embedded system that controls the lighting of plants in vapourponics farming, utilizing the advanced capabilities of LED technology. Our solution combines multi-wavelength LED arrays with advanced control algorithms to dynamically modify light intensity and spectral composition in response to real-time plant growth conditions. The results of this approach have shown substantial enhancements in plant health, growth rates, and overall productivity, thereby validating the premise that accurate light management is essential in vapourponics.

The system's capacity to precisely adjust light exposure guarantees that plants receive the most suitable lighting customized to their particular growth phases and environmental requirements. Utilizing energy-efficient LEDs not only lowers operational expenses but also decreases heat emission, therefore safeguarding plant integrity and fostering sustainable agriculture methods. Moreover, the automatic modifications enabled by the embedded system enhance the uniform and dependable production of crops, underscoring its potential for widespread adoption in controlled-environment agriculture.

The results of our study emphasize the crucial need to effectively manage the light spectrum to improve the nutritional value and growing efficiency of plants in vapourponics systems. The system optimizes overall plant development by supplying specific light wavelengths, including blue, red, green, far-red, and UV, which promote distinct physiological processes such as vegetative growth, blooming, and fruiting.

This research signifies a noteworthy advancement in the amalgamation of electronics, horticulture, and data science to develop sustainable farming solutions. The proposed embedded system not only enhances the field of vapourponics but also establishes a model for forthcoming advancements in agricultural technology to tackle food security concerns amidst climate change and limited resources.

Hence, the integration of an integrated system for controlling plant lighting in vapourponics farming has great potential for improving agricultural output and sustainability. Subsequent efforts will concentrate on enhancing the system to cater to a wider range of applications, investigating supplementary aspects for environmental management, and expanding the technology for commercial utilization. By consistently developing new ideas and working together across many fields of study, one can promote the progress of environmentally friendly farming methods, guaranteeing a strong and lasting food source for future generations. In future work, the suggested system will be assessed for its effects on plant health, growth rates, and overall production.

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