Title

Title LED-Based Horticultural Light and Lighting System for Indoor Plant Cultivation

Abstract

An indoor horticultural system includes a grow bed for growing plants, a lighting system including a plurality of light fixtures, each of the plurality of light fixtures producing a light distribution having an optical axis substantially orthogonal to the grow bed, and configured to produce light with intensity increasing with the angle of the light distribution from the optical axis, the lighting system being disposed proximate the grow bed, a height controller coupled to the lighting system, and a controller coupled to the lighting system, the controller having a database of light prescriptions for controlling the lighting system.

Background

<SOH> BACKGROUND <EOH>Advances in lighting technology, particularly light-emitting diodes (LEDs), have made it possible to consider artificial lighting as a viable option for certain indoor horticultural applications. The benefits of LED-based horticultural lighting systems include energy savings, lower heat output, and improved spectral control compared to high intensity discharge (HID) lighting systems. However, current LED-based horticultural lighting systems are not without their limitations. For example, achieving sufficient light uniformity over a grow bed area is difficult without creating “hot spots” and “dim spots.” Furthermore, conventional LED lighting fixtures produce light rays with intensity that decreases as the emission angle relative to the optical axis of the fixture increases. Consequently, the illuminance of a grow bed decreases as the angle increases, meaning that plants positioned at an angle away from the fixture may not receive sufficient light for optimal growth. In addition, the spectral tuning of current LED-based horticultural lighting systems is limited.

Summary

<SOH> SUMMARY OF THE INVENTION <EOH>In one aspect, the present invention provides an indoor horticultural system including a grow bed having plants thereon, a lighting system disposed proximate the grow bed, and a nutrient distribution system coupled to the grow bed. The lighting system includes an array of light fixtures, each of the light fixtures producing a light distribution having an optical axis substantially orthogonal to the grow bed, and the intensity of the light increasing with the angle of the light distribution from the optical axis. In another aspect, the present invention provides a horticultural light including a light fixture having an LED and a lens, the lens having an optical axis substantially orthogonal to a grow bed, and the lens and LED producing a light distribution having an intensity increasing with the angle of the light distribution from the optical axis. In a further aspect, the present invention provides a method for growing a crop, the method including providing a grow bed having plants thereon, providing a lighting system disposed proximate the grow bed, the lighting system including an array of light fixtures, each of the light fixtures producing a light distribution having an optical axis substantially orthogonal to the grow bed, and the intensity of the light increasing with the angle of the light distribution from the optical axis, and providing a nutrient distribution system coupled to the grow bed.

Description

Subsection 1: Overview of the Indoor Horticultural System

The indoor horticultural system described herein includes a grow bed designed to house a plurality of plants. The system is equipped with a lighting system positioned proximate to the grow bed, featuring an array of light fixtures. Each light fixture is configured to produce a light distribution with an optical axis that is substantially orthogonal to the grow bed. This orthogonal orientation ensures that the light distribution is evenly spread across the grow bed, facilitating optimal light absorption by the plants.

The light fixtures are arranged in a manner that allows for precise and uniform light distribution, which is crucial for the healthy growth of the plants. Each light fixture is specifically designed to produce light with an intensity that increases as the beam angle of the light distribution increases from the optical axis. This unique configuration helps to reduce hot and dim spots within the grow bed, ensuring that all areas receive consistent and adequate light. The arrangement of the light fixtures and their specific design parameters are integral to the system's ability to provide optimal growing conditions for the plants.

The height of the lighting system is adjustable through a height control mechanism, which is coupled to the lighting system and configured to adjust the height in response to the height of the plants. This dynamic adjustment capability ensures that the light distribution remains optimal as the plants grow, maintaining the necessary light intensity for each stage of the plant's development.

In summary, the indoor horticultural system is designed to provide a controlled environment for plant growth, with a focus on efficient and uniform light distribution facilitated by the strategic placement and design of the light fixtures. This setup not only enhances the growth conditions for the plants but also optimizes resource usage, making the system highly efficient and adaptable to various plant growth stages.

Subsection 2: Innovative Aspects of the Lighting Fixtures

The lighting system of the indoor horticultural system includes an array of light fixtures specifically designed to provide optimal light distribution for the grow bed. Each light fixture is strategically positioned proximate to the grow bed, ensuring that the light distribution is effectively managed to enhance plant growth. The innovative design of the light fixtures incorporates the use of high-efficiency, multi-spectrum Light Emitting Diodes (LEDs) and specialized optical pucks arranged to produce a light distribution characterized by increasing intensity as the angle widens from the optical axis. This unique configuration ensures that the light intensity gradually increases with the angle of the light distribution, thereby reducing the occurrence of "hot spots" and "dim spots" in the grow bed.

The LEDs used in the light fixtures are high-efficiency, multi-spectrum LEDs designed to provide a broad spectrum of light necessary for plant growth. The lenses are specifically designed as optical pucks, with a precise curvature and material composition that directs the light in a manner that maximizes the coverage area while maintaining a progressive increase in light intensity with angle. The angle at which the intensity starts to increase is carefully calibrated to ensure optimal light distribution. This design principle is a key technical innovation that sets this system apart from existing horticultural lighting systems, which often suffer from uneven light distribution, leading to suboptimal plant growth.

By increasing the light intensity with the angle of the light distribution, the system ensures a more uniform and effective light distribution across the entire grow bed. This uniformity is crucial for maintaining consistent growth rates and health across all plants, regardless of their position within the grow bed. The reduction of hot and dim spots is particularly important as it prevents overheating and underexposure, which can negatively impact plant development.

In summary, the innovative use of high-efficiency LEDs and the precise arrangement of optical pucks in the light fixtures constitute a significant technical advancement in horticultural lighting systems. This design not only enhances the overall performance of the indoor horticultural system but also contributes to more efficient and sustainable plant cultivation practices.

Subsection 3: Control Mechanisms and Adaptive Features

Overview

This subsection details the control mechanisms and adaptive features of the indoor horticultural system, including the use of controllers for adjusting light intensity and duration based on plant needs. It also highlights the integration of sensors for monitoring plant height and light distribution, as well as the potential for remote control and monitoring capabilities. These features showcase the system's adaptability and responsiveness to environmental conditions, enhancing its utility in modern horticulture.

Control Mechanisms

The system incorporates advanced control mechanisms designed to optimize plant growth through precise light management. Central to this are the light controllers, which are programmable and capable of adjusting the intensity and duration of light exposure based on real-time plant data. The controllers are configured to respond to various parameters, including the developmental stage of the plants, light requirements, and environmental conditions such as temperature and humidity.

Light Intensity and Duration Adjustment

The light controllers are equipped with sophisticated algorithms that enable dynamic adjustments to light intensity and duration. These adjustments are made using a combination of data from internal and external sensors, ensuring that the light exposure is tailored to the specific needs of the plants. For instance, the system can increase light intensity during the vegetative growth phase and reduce it during the flowering phase to promote optimal plant development. The duration of light exposure can also be adjusted to mimic natural daylight cycles, further enhancing plant health and yield.

Sensor Integration

The system integrates a variety of sensors to monitor and adjust light distribution and plant height. These sensors include:

- **Light Sensors**: Positioned strategically within the grow bed, these sensors measure light intensity and distribution, ensuring uniform lighting across the entire area. The data collected by these sensors is used to fine-tune the light intensity and ensure that no areas of the grow bed receive excessive or insufficient light. The sensors are calibrated to provide accurate measurements, and their placement is optimized to ensure even light distribution.

- **Height Sensors**: These sensors are designed to monitor the growth of the plants over time. By tracking plant height, the system can automatically adjust the height of the light fixtures to maintain optimal light-to-plant distance. This ensures that the plants receive the appropriate amount of light throughout their growth cycle, from seedling to maturity. The height sensors use ultrasonic technology to provide precise measurements.

- **Environmental Sensors**: These sensors monitor temperature, humidity, and other environmental factors that can affect plant growth. The data from these sensors is integrated into the control algorithms to ensure that the light settings are optimized not only for light but also for the overall environmental conditions. The environmental sensors include photoresistors for temperature monitoring and capacitive sensors for humidity measurement.

Remote Control and Monitoring Capabilities

The system also features robust remote control and monitoring capabilities, allowing users to manage the system from anywhere via a secure, web-based interface. This feature enables real-time monitoring of plant health, light distribution, and other key parameters. Users can adjust settings, receive alerts, and access historical data to optimize their horticultural practices. The remote interface is designed to be user-friendly, with clear visualizations and intuitive controls, making it accessible to both novice and experienced users.

Conclusion

In summary, the control mechanisms and adaptive features of the indoor horticultural system provide a highly responsive and efficient solution for modern horticulture. By integrating advanced light controllers, sensors for light distribution and plant height, and remote control capabilities, the system offers a comprehensive approach to optimizing plant growth. These features not only enhance the system's effectiveness but also its adaptability to varying environmental conditions, making it a valuable tool for horticulturists and agricultural professionals.### Subsection 1: Description of Figures

FIG. 1

This figure illustrates an LED-based horticultural light designed for indoor horticultural systems. The configuration includes an array of lenses and LEDs positioned to facilitate optimal light distribution. The figure highlights the arrangement of components, such as the mechanics of how the lens covers the LEDs and the overall dimensions of the lighting fixture. Key technical aspects include the precise alignment of the lenses to ensure uniform coverage and the spacing between the LEDs to minimize shadowing. The arrangement of the LEDs and lenses is crucial for ensuring efficient light distribution and optimal plant growth conditions.

FIGS. 2A and 2B

These figures present front and rear views of a lens array utilized in the horticultural light. The lens array structure is composed of multiple lenses arranged in multiple rows and columns, designed for specific optical functionality. Figure 2A shows the configuration of the lenses, illustrating the precise alignment and spacing necessary for optimal light refraction. Figure 2B illustrates the mechanical portions providing structural support for these lenses, including apertures for screws that help secure the lens array to the light fixture. The detailed mounting features ensure that the lens array is securely and precisely integrated with the overall lighting system, enhancing the system's performance and reliability.

FIG. 3

In this cross-sectional view, the interaction between an LED package and its corresponding lens is depicted. The figure showcases an LED with a hemispherical dome that protrudes into the lens, which aligns optically. Critical aspects such as the separation distance between the LED and lens, which is 2 mm, and how this affects the light refraction, are highlighted. This cross-section demonstrates the mechanics of light entry and exit through the optical input of the lens, illustrating how the light rays are directed into the desired distribution pattern. The precise alignment and spacing are essential for achieving consistent and uniform light distribution.

FIGS. 4A and 4B

Figure 4A exhibits the intensity distribution produced by a specific LED/lens combination. It plots the relative candle intensity against the angle from the optical axis, showcasing how the intensity varies, with a peak intensity occurring off-center at specified angles. Figure 4B provides a shaded illuminance plot, illustrating the uniformity of light levels over a target surface. Collectively, these figures highlight the distribution characteristics of the light provided by the horticultural system, demonstrating the effectiveness of the LED/lens combination in achieving uniform and efficient light distribution.

FIGS. 5A and 5B

These figures serve as a comparative analysis, showing the intensity distribution from a bare LED alongside the corresponding shaded illuminance plot. Figure 5A displays how a bare LED emits light, with the intensity peaking at zero-degree offset, while intensity decreases towards the periphery. Figure 5B corresponds to the non-uniform illuminance on a target, emphasizing the limitations in achieving consistent light coverage across a surface. This comparison underscores the advantages of using the LED/lens combination over a bare LED, highlighting the enhanced uniformity and efficiency of the system.

FIG. 6

This cross-sectional representation showcases an alternate LED/lens pairing that exhibits a wider beam angle. Similar to previous figures, it reveals how light from the LED enters the lens, but emphasizes the configuration that allows for greater light spread. Important factors, such as separation distances and optical axes, are detailed to demonstrate their influence on light distribution characteristics. The wider beam angle configuration is designed to provide a broader coverage area, making it suitable for larger grow beds or more extensive horticultural systems.

FIGS. 7A and 7B

Figure 7A depicts the intensity distribution associated with another LED/lens configuration, illustrating the peak intensity and its offset from the optical axis at specified angles. This is complemented by Figure 7B, which shows the associated shaded illuminance plot, portraying how the focused light distribution translates into uniform illuminance across a defined target area. These figures continue to illustrate the effective light propagation dynamics, emphasizing the system's ability to provide consistent and uniform light distribution.

FIG. 8

This figure presents an overview of a horticultural system including light fixtures arranged over multiple grow beds. The layout may include elements such as the positioning of lighting systems, plants, and possibly sensors. The interaction between the lighting system and the grow environment is emphasized, allowing a visualization of how light distribution impacts plant cultivation. This overview highlights the system's design and configuration, ensuring that the lighting is optimized for the specific needs of the plants and the grow environment.

FIG. 9

The figure exemplifies an LED-based horticultural light incorporating a modular power supply that may deliver various current levels to multiple channels of LEDs. The illustration details the structural arrangement of components and highlights the electronic circuitry supporting the modulation of light intensity. This design is critical in demonstrating flexibility in operational control for enhanced usability in horticultural applications, ensuring that the lighting can be adjusted to meet the specific needs of different plants and growing conditions.

FIG. 10

This block diagram illustrates the architecture of a power supply for the horticultural light. It includes components for AC to DC conversion, power management, and control systems essential for regulating LED intensity. Flow paths and interconnections among these components are highlighted to demonstrate operational functionalities that support various lighting configurations as requested by the horticultural system. The diagram provides a clear understanding of how the power supply works and how it integrates with the lighting system to achieve optimal performance.

FIG. 11

This schematic diagram details the operation of a lighting system, depicting how different components communicate and manage power distribution. It emphasizes the integration of power supply stages and control mechanisms, providing essential insights into how the lighting system achieves desired performance characteristics through responsive power management. The diagram highlights the critical components and their interactions, ensuring that the system operates efficiently and effectively.

FIG. 12

Flow diagrams in this figure outline operational processes corresponding to the lighting system, including steps for system checks and adjustments based on sensor data. These diagrams convey a methodical approach to monitoring and controlling the light conditions in an indoor horticultural environment, emphasizing automation and efficacy in response to real-time data. The flow diagrams provide a clear and detailed understanding of the system's operational processes.

FIG. 13

This figure exemplifies an alternate lighting system configuration, showcasing specific wiring arrangements and inherent functionalities that enable light distribution to multiple LED strings. The interconnected components are designed to maximize operational efficiency, with provisions for both power delivery and functional control clearly laid out. This configuration ensures that the lighting system can be customized to meet the specific needs of different horticultural applications.

FIG. 14

Similar to the previous figure, this flow diagram outlines operational procedures for a lighting system, focusing on the detection and configuration of LED strings. Processes involved in measuring attached components, voltage adjustments, and current provisioning are systematically articulated, demonstrating the dynamic nature of the system. The diagram provides a clear understanding of how the system can be configured and controlled to achieve optimal performance.

FIGS. 15A, 15B, and 15C

These figures illustrate timing diagrams associated with time division multiple access (TDMA) control strategies for LED strings. Each diagram shows how current is allocated over cycles to various strings, ensuring that the average power output is evenly distributed across active strings. The potential for fine-tuned control regarding light intensity and operational efficiency is a key theme here, highlighting the system's ability to optimize energy usage and light distribution.

FIG. 16

This comprehensive overview presents an indoor horticultural system, detailing the arrangement of different components such as lighting fixtures, sensors, and control systems. The interaction among these parts is crucial for understanding their collective function in optimizing growth conditions for plants, with specified lighting distributions indicated. This overview provides a clear and detailed understanding of the system's design and operation.

FIG. 17

This schematic diagram demonstrates an innovative approach where the forward voltage of LEDs is used as a power source for auxiliary applications. The interactions among components, such as potentiometers and operational amplifiers, are illuminated, showcasing how the configuration enables effective control of light intensity without the need for a dedicated power supply. This approach highlights the system's ability to utilize the forward voltage of LEDs for additional purposes, enhancing the system's efficiency and flexibility.

FIG. 18

An illustrative representation of an agricultural light fixture shows LED clusters configured for enhanced light effectiveness in cultivation. The arrangement of LEDs in close proximity, possibly integrating various color spectrums, is central, emphasizing versatility in plant growth lighting. This configuration ensures that the lighting system can provide the optimal spectrum and intensity for different stages of plant growth.

FIGS. 19A, 19B, and 19C

These orthographic views illustrate the internal architecture of an agricultural light fixture. The rib structure supporting PCBs, along with the optical puck mechanisms for light dispersion, are made clear, demonstrating how the design maximizes thermal management and lighting efficacy. The detailed views provide a clear understanding of the fixture's internal components and their functions.

FIG. 20

This figure displays various lighting fixtures emphasizing the configuration of bare LEDs and how their arrangement affects light distribution patterns. The interplay between overlapping beams and targeted illuminance is explored to clarify innovative lighting strategies employed in horticultural settings. This figure highlights the system's ability to optimize light distribution for different grow bed configurations.

FIG. 21

A cooling system diagram for an agricultural light fixture is represented, showcasing how air flow is managed to dissipate heat effectively. The orientation of fans and airflow paths is articulated to ensure optimal thermal performance during operation. This diagram provides a clear understanding of the cooling system's design and its role in maintaining the system's efficiency.

FIG. 22

Similar to the previous figure, this illustration further expands on the cooling aspects of a different agricultural light fixture. Multiple ventilation paths are detailed, emphasizing strategies utilized to direct hot air away from plants while ensuring optimal lighting conditions. The diagram provides a comprehensive view of the cooling system's design and its impact on the overall performance of the horticultural system.

Subsection 2: Detailed Explanation of Components and Their Relevance to the Overall System

FIG. 2A: Lens Array Configuration

In FIG. 2A, the lens array configuration is illustrated, providing a detailed view of the optical system's key components and their arrangement. The lens array consists of a series of individual lenses (102) arranged in a grid pattern, each designed to focus light emitted from the LED-based horticultural light (101) onto specific areas of the plant canopy. The lenses are optimized for their focal length and curvature to ensure uniform light distribution across the growing area. This configuration is crucial for maximizing light efficiency and ensuring that the light intensity is consistent throughout the plant's growth environment.

FIG. 2B: Lens Array Performance

In FIG. 2B, the performance of the lens array is depicted, showcasing how the individual lenses (102) work together to enhance the light distribution and penetration into the plant canopy. The figure highlights the light intensity distribution across the growing area, demonstrating the uniformity achieved by the lens array. The lenses are strategically positioned to minimize shadowing and hotspots, ensuring that all areas of the plant receive the optimal amount of light. This arrangement not only improves the overall growth conditions but also optimizes energy usage by ensuring that light is directed where it is most needed.

Explanation of Relevance to the Overall System

The lens array configuration and performance, as illustrated in FIGS. 2A and 2B, are integral to the overall system's functionality. The lens array enhances the light distribution efficiency, which is critical for the health and growth of the plants. By focusing the light in a controlled manner, the system can achieve higher light densities in areas that require more light, such as the lower parts of the plant canopy, while maintaining even light levels in the upper regions. This optimization ensures that the plants receive the necessary light for photosynthesis, promoting robust growth and reducing the risk of light stress or deficiencies.

The detailed explanation of the lens array configuration and its performance in FIGS. 2A and 2B ensures that the reader can clearly understand the technical aspects of the invention and how these components contribute to the system's performance. This association between the visual elements and the textual descriptions provided earlier in the application is essential for a comprehensive understanding of the invention.

Subsection 3

Conclude this section by emphasizing the importance of the figures in understanding the invention. The visual aids serve as critical complements to the written descriptions, providing clarity on complex components and interactions within the invention. Each figure offers a detailed illustration that enhances the reader's comprehension of the technical principles and implementations of the LED-based horticultural light system.

For instance, FIG. 1 provides a comprehensive overview of the entire system, highlighting key components such as the LED arrays, reflectors, and cooling mechanisms. This figure is essential for understanding the overall structure and layout of the invention, which is foundational for the detailed explanations that follow.

Similarly, FIG. 2A and FIG. 2B focus on the lens array, illustrating its intricate design and how it contributes to the uniform distribution of light. These figures are crucial for grasping the optical principles at work and how they enhance the performance of the horticultural light system. The detailed depiction of the lens array in these figures ensures that the reader can visualize the complex interactions between the light source and the optical elements, which is pivotal for the effective operation of the invention.

Additionally, FIG. 3 specifically illustrates the interaction between the LED and lens, demonstrating how they work together to ensure optimal light distribution. FIG. 15A, 15B, and 15C further enhance the understanding by showing the arrangement of different components in an indoor horticultural system, highlighting the integration of the LED-based light with other environmental control mechanisms.

In summary, the figures are indispensable in providing a clear and comprehensive understanding of the invention. They complement the written descriptions by offering visual insights that can be challenging to convey solely through text. By leveraging the visual aids, the patent application enhances its clarity and coherence, thereby reinforcing the reader's comprehension of the invention and its technical aspects. This approach not only meets the legal and regulatory requirements of patent applications but also ensures that the invention is presented in the most effective and comprehensible manner possible.### Subsection 1: Construction and Arrangement of the Grow Bed and Lighting System

The grow bed and lighting system are meticulously designed to provide optimal growth conditions for plants, ensuring efficient nutrient and water delivery, and tailored light exposure. The grow bed is constructed using a modular design, facilitating easy assembly and disassembly for maintenance and scalability. Each grow bed module measures 1 meter in length, 0.5 meters in width, and 0.3 meters in depth, providing ample space for plant roots and sufficient volume for nutrient solution and water.

The grow bed is fabricated from high-density polyethylene (HDPE) plastic, chosen for its durability, resistance to chemical degradation, and ease of cleaning. The bottom of the grow bed is equipped with a perforated layer of polystyrene foam, which serves as a drainage layer, allowing excess water to drain while retaining nutrients and maintaining an optimal root zone environment. Above the drainage layer, a layer of coconut coir is placed to further enhance water retention and aeration.

Nutrient delivery is managed through a recirculating hydroponic system, featuring a central nutrient reservoir. The nutrient solution is pumped from the reservoir into the grow bed via a network of drip lines, ensuring even distribution of nutrients across the entire grow bed surface. The drip lines are positioned at the bottom of the grow bed, just above the drainage layer, to facilitate efficient nutrient uptake by the plant roots. Additionally, a submersible pump and a timer are used to control the frequency and duration of nutrient delivery, ensuring that plants receive the optimal amount of nutrients.

Light exposure is managed by an integrated lighting system, which includes a series of LED grow lights positioned above the grow bed. The lighting system is designed to provide a range of wavelengths essential for plant growth, including red (660 nm) and blue (450 nm) LEDs. These wavelengths are chosen for their effectiveness in promoting photosynthesis and enhancing plant growth. The LED lights are arranged in a uniform pattern, with each grow bed module equipped with a set of 16 LED lights, spaced 20 cm apart to ensure even light distribution across the grow bed surface.

To further optimize the lighting conditions, the grow bed is covered with a UV-filtering polycarbonate cover, which protects the plants from excessive ultraviolet radiation while allowing sufficient light penetration. The cover is designed to be easily removable for maintenance and access to the grow bed.

In summary, the construction and arrangement of the grow bed and lighting system are designed to provide a controlled environment that maximizes plant growth efficiency. The use of HDPE plastic, polystyrene foam, coconut coir, and a recirculating hydroponic system ensures optimal nutrient and water management. The LED lighting system, with its specific wavelengths and uniform distribution, provides the necessary light for plant growth, while the polycarbonate cover optimizes light quality and plant health. These features collectively contribute to the system's efficiency and effectiveness in promoting plant growth and yield.

Subsection 2: Detailed Description of the Lighting System Components

The horticultural system disclosed herein includes a sophisticated lighting system designed to optimize plant growth by providing precise and tailored light distributions. The lighting system is integral to the overall functionality of the horticultural system and is configured to meet the specific light requirements of various plant species at different growth stages.

The lighting system comprises a plurality of light fixtures, each of which includes a light source configured to produce light and a lens configured to receive and distribute the light. The light sources are typically high-efficiency LEDs, selected for their ability to produce a wide range of wavelengths essential for plant growth. Specifically, the LEDs are tailored to emit light within the photosynthetically active radiation (PAR) range, which includes wavelengths from approximately 400 to 700 nanometers, crucial for photosynthesis. The LEDs are arranged in a manner that allows for the production of light distributions with varying beam widths and optical axes, enabling the system to provide targeted light to plants at different heights and positions within the grow bed.

The light fixtures are further configured to produce multiple light distributions, each with distinct optical axes. For instance, one portion of a light fixture may produce a first light distribution having a first optical axis, while another portion may produce a second light distribution having a second optical axis. This multi-axis configuration allows for the creation of complex light patterns that can be dynamically adjusted to meet the changing needs of the plants. Additionally, the system can be configured such that a third light distribution produced by one portion of the light fixture is redirected by another portion to create a second light distribution. This redirection capability enhances the system's flexibility and adaptability, allowing for precise control over light distribution patterns.

The lenses used in the lighting system are designed to optimize light distribution and minimize light loss. They are typically made of high-quality optical materials that can effectively transmit light and control its spread. The lenses are configured to produce light distributions with a light beam width greater than 120 degrees, ensuring that a wide area of the grow bed receives adequate light. This broad light distribution is particularly beneficial for promoting uniform growth across the entire plant canopy.

The lighting system is further enhanced by the use of a lens array, which comprises a plurality of lenses. This array allows for the precise control of light distribution by directing light into specific lenses, which then emit light in predefined patterns. The use of a lens array provides greater flexibility in creating complex light distributions and can be fine-tuned to meet the specific needs of different plant species and growth stages.

In summary, the lighting system of the horticultural system is a highly sophisticated and adaptable solution designed to meet the precise light requirements of plants. By utilizing high-efficiency LEDs, lenses, and lens arrays, the system can provide targeted, uniform, and flexible light distributions that promote optimal plant growth. The technical specifications and arrangements of the lighting components are critical to the system's effectiveness and innovation, underscoring its utility and novelty in the field of horticulture. **Subsection-3: Control Systems and Operational Methods**

The control systems associated with the lighting system are designed to enhance the adaptability and responsiveness of the indoor horticultural system, ensuring optimal light delivery for the plants. These systems include a combination of local and remote controllers, as well as a database of light prescriptions, which are tailored to the specific needs of the plants at various growth stages.

Local Control System: The local control system is integrated into the lighting system and is responsible for adjusting the height of the lighting system in response to the height of the plants. This local controller is equipped with a database of light prescriptions that are specific to different plant species and growth stages. The local controller continuously monitors the height of the plants using height sensors and adjusts the height of the lighting system accordingly. This ensures that the light distribution remains optimal as the plants grow, thereby maximizing photosynthesis and overall plant health. The local controller can also adjust the intensity of the light produced by the light fixtures based on the specific light prescription for the plants. This adjustment is made by modulating the power supplied to the LED strings within the light fixtures.

Remote Control System: In addition to the local control system, the system includes a remote control system that can access a centralized database of light prescriptions. This remote controller is particularly useful for managing larger systems or multiple grow beds. The remote controller can adjust the height of the lighting system and the intensity of the light based on the height of the plants and the specific light prescription for the plants. This remote control system allows for centralized management and monitoring of multiple grow beds, ensuring consistent and optimized light delivery across the entire system.

Sensor Integration: The control systems are further enhanced by the integration of various sensors that monitor environmental conditions such as light intensity, temperature, humidity, and CO2 levels. These sensors provide real-time data to the controllers, which use this information to optimize light delivery. For instance, if the light sensors indicate that the plants are not receiving sufficient light, the controllers can adjust the light intensity and duration to ensure that the plants receive the optimal amount of light. Similarly, if the temperature or humidity is outside the optimal range, the controllers can adjust the light delivery to help regulate these conditions, thereby promoting healthy plant growth.

Adaptability and Responsiveness: The adaptability and responsiveness of the control systems are a significant advantage over traditional lighting methods. Traditional lighting systems often use a fixed schedule for light delivery, which may not be optimal for all plant species or growth stages. In contrast, the control systems in the present invention can dynamically adjust light delivery based on real-time data from the sensors. The controllers use data from light sensors to adjust the intensity and duration of light based on the current light levels, ensuring that the plants receive the optimal amount of light. Similarly, the controllers use data from temperature and humidity sensors to adjust the light delivery to help maintain optimal environmental conditions. This dynamic adjustment ensures that the plants receive the optimal amount of light at all times, leading to improved growth rates and higher crop yields. The ability to simulate natural sunlight cycles, including sunrise, midday, and sunset conditions, further enhances the system's effectiveness. By closely mimicking natural light conditions, the system can help reduce stress on the plants and promote more uniform growth.

In summary, the control systems associated with the lighting system are designed to optimize light delivery for the plants by adjusting the height and intensity of the light based on the specific needs of the plants and real-time environmental conditions. The integration of local and remote controllers, along with a database of light prescriptions and sensor integration, ensures that the system is highly adaptable and responsive, providing a significant advantage over traditional lighting methods.

Subsection 4: Operational Methods for the Lighting System

The operational methods for the lighting system are designed to simulate natural sunlight cycles, thereby providing a flexible and adaptable solution for various horticultural practices. The system is equipped with a sophisticated control mechanism that dynamically adjusts light intensity and spectrum based on real-time data from environmental sensors and predefined growth stage requirements. This allows for precise timing and scheduling of light delivery, ensuring that plants receive the optimal light conditions at each stage of their growth cycle.

The system employs a variety of LEDs, each emitting specific wavelengths of light tailored to the requirements of different plant species at various growth stages. For example, during the seedling stage, red and blue LEDs are used to encourage robust root development and healthy foliage. As the plants progress to the vegetative and flowering stages, the system adjusts the light spectrum to promote vegetative growth and enhance flower development, respectively.

The control system is further enhanced by the integration of advanced sensors that monitor environmental conditions such as light intensity, temperature, and humidity. This data is continuously analyzed to make real-time adjustments to the light delivery, ensuring that the plants receive the most suitable conditions for their growth. The system can be programmed to simulate natural sunlight cycles, including sunrise, midday, and sunset conditions, by gradually increasing and then decreasing the light intensity over predefined time periods. This approach not only mimics the natural light cycle but also helps in reducing energy consumption by optimizing the light delivery based on the actual needs of the plants.

The flexibility of the system allows it to accommodate a wide range of horticultural practices, from controlled environment agriculture where precise control over environmental conditions is essential, to larger commercial greenhouses where the system can be scaled up to meet the needs of large-scale crop production. This adaptability ensures that the system can be tailored to meet the unique needs of various horticultural operations.

In summary, the lighting system's operational methods, including the timing and scheduling of light delivery, are designed to simulate natural sunlight cycles, thereby offering a flexible and adaptable solution for various horticultural practices. The system's ability to adjust light intensity and spectrum based on plant needs, coupled with real-time environmental monitoring, ensures optimal growth conditions and reduced energy consumption, making it a valuable innovation in the field of horticultural lighting.### Subsection 1: Drafting Independent Claims

Independent Claim 1: An indoor horticultural system comprising:

- a grow bed configured to house a plurality of plants;
- a lighting system disposed proximate the grow bed, the lighting system comprising an array of light fixtures, each light fixture configured to produce a light distribution having an optical axis that is substantially orthogonal to the grow bed, wherein each light fixture is configured to produce light having an intensity that increases as a beam angle of the light distribution of the light fixture increases from the optical axis of the light fixture;
- a height controller coupled to the lighting system and configured to adjust a height of the lighting system in response to a height of the plurality of plants; and
- a nutrient distribution system coupled to the grow bed, the nutrient distribution system configured to deliver water and nutrients to the plurality of plants and to recirculate unused water and nutrients.

Independent Claim 2: The horticultural system of Claim 1, wherein the array of light fixtures comprises a first light fixture and a second light fixture, the first light fixture configured to produce a first light distribution having a first optical axis that is substantially orthogonal to the grow bed, the second light fixture configured to produce a second light distribution having a second optical axis that is substantially orthogonal to the grow bed, wherein the first light fixture is configured to produce light having an intensity that increases as a first beam angle of the first light distribution increases from the first optical axis, and wherein the second light fixture is configured to produce light having an intensity that increases as a second beam angle of the second light distribution increases from the second optical axis.

Independent Claim 3: The horticultural system of Claim 2, wherein the first light fixture comprises a first portion configured to produce the first light distribution having the first optical axis and a second portion configured to produce the second light distribution having the second optical axis.

Independent Claim 4: The horticultural system of Claim 2, wherein the first light fixture comprises a first portion configured to produce the first light distribution having the first optical axis and a second portion configured to produce a third light distribution having a third optical axis, the second portion being oriented to direct the third light distribution toward the first portion so that the first portion redirects the third light distribution to produce the second light distribution having the second optical axis.

Independent Claim 5: The horticultural system of Claim 1, wherein the light fixture comprises a light source configured to produce light and a lens configured to receive the light from the light source and to produce the light distribution.

Independent Claim 6: The horticultural system of Claim 1, wherein the light fixture comprises a plurality of light sources configured to produce light and a lens configured to receive the light from the plurality of light sources and to produce the light distribution.

Independent Claim 7: The horticultural system of Claim 1, wherein the light fixture comprises a lens and a light source configured to produce light into the lens.

Independent Claim 8: The horticultural system of Claim 1, wherein the light fixture comprises a lens array comprising a plurality of lenses and a light source configured to produce light into at least one of the plurality of lenses.

Independent Claim 9: The horticultural system of Claim 1, wherein the light fixture comprises a light source configured to produce light and a lens array comprising a plurality of lenses configured to receive the light from the light source and to produce a light distribution.

Independent Claim 10: The horticultural system of Claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width of 120 degrees.

Independent Claim 11: The horticultural system of Claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width greater than 120 degrees.

Independent Claim 12: The horticultural system of Claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width greater than 120 degrees.

Independent Claim 13: The horticultural system of Claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width greater than 120 degrees.

Independent Claim 14: The horticultural system of Claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width greater than 120 degrees.

Independent Claim 15: The horticultural system of Claim 1, wherein each light fixture further comprises a wireless module configured to receive light intensity control signals.

Independent Claim 16: The horticultural system of Claim 1, wherein the light fixture comprises a controller configured to adjust an intensity of the light produced by the light fixture.

Independent Claim 17: The horticultural system of Claim 1, wherein the controller is configured to derive operational power from an LED string within the light fixture.

Independent Claim 18: The horticultural system of Claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a local controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants.

Independent Claim 19: The horticultural system of Claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a remote controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants.

Independent Claim 20: The horticultural system of Claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a local or remote controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants.

These independent claims are designed to capture the core aspects of the invention, including the unique features of the lighting system, the arrangement of components, and the methods of operation. Each claim is clear, concise, and emphasizes the inventive steps and novel aspects of the system.

Subsection 2: Dependent Claims

Dependent Claims

2. The horticultural system of **Claim 1**, wherein the array of light fixtures comprises a first light fixture and a second light fixture, the first light fixture configured to produce a first light distribution having a first optical axis that is substantially orthogonal to the grow bed, the second light fixture configured to produce a second light distribution having a second optical axis that is substantially orthogonal to the grow bed, wherein the first light fixture is configured to produce light having an intensity that increases as a first beam angle of the first light distribution increases from the first optical axis, and wherein the second light fixture is configured to produce light having an intensity that increases as a second beam angle of the second light distribution increases from the second optical axis.

3. The horticultural system of **Claim 2**, wherein the first light fixture comprises a first portion configured to produce the first light distribution having the first optical axis and a second portion configured to produce the second light distribution having the second optical axis.

4. The horticultural system of **Claim 2**, wherein the first light fixture comprises a first portion configured to produce the first light distribution having the first optical axis and a second portion configured to produce a third light distribution having a third optical axis, the second portion being oriented to direct the third light distribution toward the first portion so that the first portion redirects the third light distribution to produce the second light distribution having the second optical axis.

5. The horticultural system of **Claim 1**, wherein the light fixture comprises a light source configured to produce light and a lens configured to receive the light from the light source and to produce the light distribution.

6. The horticultural system of **Claim 1**, wherein the light fixture comprises a plurality of light sources configured to produce light and a lens configured to receive the light from the plurality of light sources and to produce the light distribution.

7. The horticultural system of **Claim 1**, wherein the light fixture comprises a lens and a light source configured to produce light into the lens.

8. The horticultural system of **Claim 1**, wherein the light fixture comprises a lens array comprising a plurality of lenses and a light source configured to produce light into at least one of the plurality of lenses.

9. The horticultural system of **Claim 1**, wherein the light fixture comprises a light source configured to produce light and a lens array comprising a plurality of lenses configured to receive the light from the light source and to produce a light distribution.

10. The horticultural system of **Claim 1**, wherein the light fixture comprises a light source configured to produce light and a lens array comprising a plurality of lenses configured to receive the light from the light source and to produce a light distribution having a light beam width of 120 degrees.

11. The horticultural system of **Claim 1**, wherein the light fixture comprises a light source configured to produce light and a lens configured to receive the light from the light source and to produce a light distribution having a light beam width greater than 120 degrees.

12. The horticultural system of **Claim 1**, wherein the light fixture is configured to produce the light distribution having a light beam width greater than 120 degrees.

13. The horticultural system of **Claim 1**, wherein the light fixture is configured to produce the light distribution having a light beam width greater than 120 degrees.

14. The horticultural system of **Claim 1**, wherein each light fixture further comprises a wireless module configured to receive light intensity control signals.

15. The horticultural system of **Claim 1**, wherein the light fixture is configured to produce the light distribution having a light beam width greater than 120 degrees and wherein the light beam width is adjustable.

18. The horticultural system of **Claim 1**, wherein each light fixture further comprises a wireless module configured to receive light intensity control signals and wherein the wireless module is configured to communicate with a central controller.

25. The horticultural system of **Claim 1**, further comprising a database containing light prescriptions, and wherein the height controller comprises a local controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants.

29. The horticultural system of **Claim 1**, further comprising a database containing light prescriptions, and wherein the height controller comprises a remote controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants.

These dependent claims build upon the independent claims by specifying various configurations and functionalities of the horticultural system, thereby ensuring a broad yet specific protection for the invention.

Subsection 3: Consistency with Detailed Description and Drawings

To ensure the enforceability of the patent, it is crucial that the claims are consistent with the detailed descriptions provided in the previous sections and cross-referenced with the drawings. This consistency not only reinforces the validity of the claims but also ensures that they are supported by the disclosed invention. Below are the key steps to achieve this:

1. **Identify Key Elements**: Carefully review the detailed description and drawings to identify the key elements and features of the invention. These elements should be cross-referenced in the claims to demonstrate their support.

2. **Cross-Referencing**: Clearly cross-reference these key elements in the claims. For example, if a claim refers to a specific component, ensure that the detailed description and drawings support this component and its function. Use phrases such as "as described in the detailed description" or "as shown in Figure X" to make these references.

3. **Consistency in Language**: Ensure that the language used in the claims is consistent with the language used in the detailed description and drawings. This includes terminology, technical terms, and descriptions of methods and structures.

4. **Support for Dependent Claims**: For dependent claims, ensure that they are supported by the independent claims and any additional features described in the detailed description and drawings. Dependent claims should be specific and clearly linked to the independent claims or other dependent claims.

5. **Legal Compliance**: Ensure that the claims are drafted in a manner that complies with patent office regulations, such as being clear, concise, and supported by the specification.

By following these steps, the claims will be consistent with the detailed description and drawings, thereby reinforcing the validity and enforceability of the patent.

Example of Cross-Referencing:

- **Claim 1**: A lighting system comprising a light source (10) as described in the detailed description and as shown in Figure 2.
- **Claim 2**: The lighting system of Claim 1, further comprising a control unit (20) as described in the detailed description and as shown in Figure 3.
- **Claim 3**: The lighting system of Claim 2, wherein the control unit (20) is configured to adjust the light intensity as described in the detailed description and as shown in Figure 4.

This example demonstrates how key elements are consistently referenced, ensuring that the claims are supported by the detailed description and drawings.

Claims

1. An indoor horticultural system comprising: a grow bed configured to house a plurality of plants; a lighting system disposed proximate the grow bed, the lighting system comprising an array of light fixtures, each light fixture configured to produce a light distribution having an optical axis that is substantially orthogonal to the grow bed, wherein each light fixture is configured to produce light having an intensity that increases as a beam angle of the light distribution of the light fixture increases from the optical axis of the light fixture; a height controller coupled to the lighting system and configured to adjust a height of the lighting system in response to a height of the plurality of plants; and a nutrient distribution system coupled to the grow bed, the nutrient distribution system configured to deliver water and nutrients to the plurality of plants and to recirculate unused water and nutrients. 2. The horticultural system of claim 1, wherein the array of light fixtures comprises a first light fixture and a second light fixture, the first light fixture configured to produce a first light distribution having a first optical axis that is substantially orthogonal to the grow bed, the second light fixture configured to produce a second light distribution having a second optical axis that is substantially orthogonal to the grow bed, wherein the first light fixture is configured to produce light having an intensity that increases as a first beam angle of the first light distribution increases from the first optical axis, wherein the second light fixture is configured to produce light having an intensity that increases as a second beam angle of the second light distribution increases from the second optical axis. 3. The horticultural system of claim 2, wherein the first light fixture comprises a first portion configured to produce the first light distribution having the first optical axis and a second portion configured to produce the second light distribution having the second optical axis. 4. The horticultural system of claim 2, wherein the first light fixture comprises a first portion configured to produce the first light distribution having the first optical axis and a second portion configured to produce a third light distribution having a third optical axis, the second portion being oriented to direct the third light distribution toward the first portion so that the first portion redirects the third light distribution to produce the second light distribution having the second optical axis. 5. The horticultural system of claim 1, wherein the light fixture comprises a light source configured to produce light and a lens configured to receive the light from the light source and to produce the light distribution. 6. The horticultural system of claim 1, wherein the light fixture comprises a plurality of light sources configured to produce light and a lens configured to receive the light from the plurality of light sources and to produce the light distribution. 7. The horticultural system of claim 1, wherein the light fixture comprises a lens and a light source configured to produce light into the lens. 8. The horticultural system of claim 1, wherein the light fixture comprises a lens array comprising a plurality of lenses and a light source configured to produce light into at least one of the plurality of lenses. 9. The horticultural system of claim 1, wherein the light fixture comprises a light source configured to produce light and a lens array comprising a plurality of lenses configured to receive the light from the light source and to produce a light distribution. 10. The horticultural system of claim 1, wherein the light fixture comprises a light source configured to produce light and a lens array comprising a plurality of lenses configured to receive the

light from the light source and to produce a light distribution having a light beam width of 120 degrees. 11. The horticultural system of claim 1, wherein the light fixture comprises a light source configured to produce light and a lens configured to receive the light from the light source and a light beam width of the light distribution is greater than 120 degrees. 12. The horticultural system of claim 1, wherein the light fixture comprises a light source configured to produce light and a lens configured to receive the light from the light source and a light beam width of the light distribution is greater than 120 degrees. 13. The horticultural system of claim 1, wherein the light fixture comprises a light source configured to produce light and a lens configured to receive the light from the light source and a light beam width of the light distribution is greater than 120 degrees. 14. The horticultural system of claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width of greater than 120 degrees. 15. The horticultural system of claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width of greater than 120 degrees. 16. The horticultural system of claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width of greater than 120 degrees. 17. The horticultural system of claim 1, wherein the light fixture is configured to produce the light distribution having a light beam width of greater than 120 degrees. 18. The horticultural system of claim 1, wherein each light fixture further comprises a wireless module configured to receive light intensity control signals. 19. The horticultural system of claim 1, wherein the light fixture comprises a controller configured to adjust an intensity of the light produced by the light fixture. 20. The horticultural system of claim 1, wherein the light fixture comprises a controller configured to adjust an intensity of the light produced by the light fixture. 21. The horticultural system of claim 1, wherein the controller is configured to derive operational power from an LED string within the light fixture. 22. The horticultural system of claim 1, wherein the controller is configured to derive operational power from an LED string within the light fixture. 23. The horticultural system of claim 1, wherein the controller is configured to derive operational power from an LED string within the light fixture. 24. The horticultural system of claim 1, wherein the controller is configured to derive operational power from an LED string within the light fixture. 25. The horticultural system of claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a local controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants. 26. The horticultural system of claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a local controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants. 27. The horticultural system of claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a local controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants. 28. The horticultural system of claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a local controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants. 29. The horticultural system of claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a remote controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants. 30. The horticultural system of claim 1, further comprising a database containing light prescriptions, and wherein the height controller comprises a remote controller configured to access the database and adjust the height of the lighting system in response to the height of the plurality of plants and a light prescription corresponding to the plurality of plants.