



Sensor-Based Smart Greenhouse Technology for Protected Crop Cultivation

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INTRODUCTION

Protection cultivation is a valuable technique used for growing high value crops horticulture in a controlled or partially controlled environment. Greenhouse provides protection from adverse climatic conditions and manipulation of key factors like temperature, relative humidity, irrigation, nutrition, light and carbon dioxide concentration. High-value crops like tomatoes, capsicums, cucumbers, lettuces, strawberries, flowers, herbs and nursery plants can be grown in greenhouse environment provided that proper environmental conditions are created. Traditional greenhouse management relies heavily on manual observations and irrigation/ventilation schedules which are pre-determined. But the environment in a greenhouse is quite dynamic due to rapid changes throughout the day due to varying sunlight intensity, external temperature, humidity and crop transpiration rate. It is thus possible that these rapid changes are not captured through manual observation and can result in excessive irrigation, poor ventilation, high humidity and improper temperature regime that may harm the crop growth.

The sensor based smart greenhouse technology makes use of sensors that monitor key factors and collect information that is used to make decisions regarding management of greenhouse environment. The sensors provide real time data, controller analyze this data and automated equipment takes action based on pre-determined/intelligent control policies. The resulting system provides a continuous cycle of measurement, analysis, decision-making and action, which forms the basis of precision protected cultivation.

2. Description of Sensor-Based Smart Greenhouse

The sensor-based smart greenhouse is an enclosed facility which utilizes sensors, controllers, communication means and automated machinery to monitor and control the conditions in the greenhouse where crops are grown. In general, the purpose of this type of greenhouse is to maintain the required conditions for growing of crops at their optimum level.



The sensors that are put inside the greenhouse can measure various parameters including air temperature, relative humidity, light intensity, CO₂ concentration, moisture content of the soil or substrate, EC, and pH level. Information from the sensors is sent to the controller or digital platform. Then, the controller makes comparison of the information gathered with the requirements for crops and turns on the relevant equipment if the condition changes.

For instance, when the root zone moisture falls to a certain value, then the controller may turn on the water pump and water the plants. Also, if there is excess heat in the greenhouse, the ventilation fans, roof vents, cooling pads, and other systems may be used. In the same way, the system of fertigation may also be controlled according to the needs of the crops and the nutrient content of the irrigation.

3. Major Components of a Sensor-Based Smart Greenhouse

The major components of a sensor-based smart greenhouse are sensors, control unit, actuators,

communication technology, software and automated crop-management equipment. The sensors form the data collection component of the system since they continually collect the required information.

The control unit is the decision-making component of the system. It collects information provided by different sensors and analyzes this information using algorithms programmed within it. PLCs, microcontrollers and computer systems can be used in order to analyze the collected data.

The actuator is a device which performs necessary physical tasks based on commands received from the controller. Irrigation pumps, solenoid valves, ventilation fans, motors, heating systems, cooling systems, fogging systems, fertigation systems, shade screens and automated vents are examples of actuators in smart greenhouses. The communication technology provides the link between the sensors, the controller and the users. Information is transferred through wired or wireless networks and displayed on computers or mobile devices.

4. Environmental Sensors

Temperature is one of the most critical environmental factors influencing crop growth in greenhouses. Sensors measure temperature and help control the ventilation, heating, and cooling systems. The presence of adequate temperature levels is necessary for the processes of photosynthesis, respiration, flowering, fruit development, and overall crop yield.

Relative humidity sensors are used to measure the moisture level in the greenhouse environment. Increased humidity leads to an increased risk of development of fungi and bacteria, while low humidity increases transpiration and water stress. For these reasons, it is important to keep track of humidity for the maintenance of the suitable microclimate.

Light sensors measure the amount of sunlight received by the crop. This data can be used for managing the shading and supplementary lighting systems. It is especially necessary for crops that need high light intensity or when the amount of light is reduced during specific periods.

Sensors can also monitor the level of CO₂ in the greenhouse environment. As carbon dioxide is required for photosynthesis and its concentration decreases when the activity of crops is high and ventilation is insufficient, this data will improve environmental management.

5. Soil and Root Zone Sensors

The root zone plays an extremely important role in determining plant growth and production. Moisture sensors are helpful for measuring the water content in the root zone and enabling irrigation according to the real moisture conditions instead of a fixed schedule.

Electrical conductivity sensors can be used for detecting the concentration of dissolved salts and nutrients in the root zone solution or the fertigation process. High electrical conductivity may show that there is

salt buildup, while low electrical conductivity may mean low nutrient concentration. Finally, pH sensors play an important role in soilless production and the fertigation process since the availability of nutrients is dependent on pH.

6. Automated Irrigation and Fertigation

Probably, one of the most important applications of sensors in protected agriculture is the automated irrigation. The traditional irrigation that is carried out at certain time periods could provide too much or too little water depending on the needs of the plants. With sensors, it becomes possible to decide whether irrigation should be done according to the moisture in the soil.

When the moisture level in the soil drops to certain parameters set in advance, the control system can turn on the irrigation system, and once the required moisture level is achieved, irrigation stops. It can help to save water and create stable moisture conditions for the plant roots.

Water-soluble fertilizers can be supplied to plants during irrigation using the automated fertigation system, taking into account electrical conductivity, pH, growth stage of the crop, and irrigation needs.

7. Automated Temperature and Humidity Control

Proper temperature and humidity management is critical to achieve proper microclimate in the greenhouse. Whenever temperature goes beyond the desirable range, automated roof and side vents, ventilation fans and cooling pads/foggers can be employed depending on the climate.

During cold periods, heating and thermal screens can be used economically. The humidity level can be controlled by means of ventilation, heating, irrigation, and other environmental controls. Proper temperature and humidity levels facilitate healthy growth of plants and minimize the chances of environmental stress and diseases.

8. Light Control

The light intensity and day length affect such processes as photosynthesis, morphology, flowering, fruiting, etc. Modern sensors systems can measure light intensity and activate shading screens whenever there is an excess of radiation. Under conditions of low light intensity, supplemental lighting can be provided in high-value systems.

Modern smart greenhouse systems may incorporate LED lighting with automated controls. Lighting can be regulated according to the needs of the plants, their growth stage, and natural radiation. This technology can enhance light use efficiency although energy costs and economic feasibility have to be taken into account.

9. Internet of Things for Smart Greenhouses

IoT technology has greatly enhanced the opportunities for greenhouse automation. The IoT technology involves connectivity of various sensors and devices via a digital network. Continuous gathering and transfer of information about environmental factors to cloud computing platforms is possible.

Information about greenhouses can be accessed by farmers or greenhouse managers using computers or mobile phones. Notifications can be provided when the temperature, humidity, moisture or any other parameters go beyond the preset levels. Remote control can be especially helpful for large greenhouses situated at distances from the farm house. Historical data can also be analyzed to reveal trends in crop development and environmental parameters. Such data can help improve the irrigation schedules and crop climate control.

10. Artificial Intelligence and Decision Making Based on Data

The use of artificial intelligence and machine learning methods can enhance the management of smart greenhouses. Large amounts of environmental and crop data can

be analyzed for the identification of the connections between environment and crop performance.

AI systems can help to predict the needs for irrigation, crop development, risks of diseases and harvest dates. Machine-vision technologies can analyze images of leaves, stems, flowers and fruits to identify symptoms associated with diseases, pests, nutrient deficiencies or abnormal growth. However, the effectiveness of AI systems depends on the quality and quantity of data used for training and validation. Crop-specific and location-specific calibration is therefore important before applying such systems commercially.

11. Application in Vegetables

The sensor-based smart greenhouse technology is highly relevant in the cultivation of valuable vegetables like tomatoes, cucumbers, capsicum, lettuce and leafy vegetables. The crops are highly sensitive to changes in temperature, humidity, availability of water and nutrient content.

Automated fertigation system in the tomato and capsicum would be helpful in delivering water and nutrients based on requirements of the crops and the sensors can help regulate climate. Automated irrigation and ventilation would help in the regulation of climatic conditions required for vegetative and reproductive growth of cucumber crops. Automated irrigation and moisture regulation can help in maintaining uniformity in the growth and quality of leafy vegetables. The smart greenhouses can also help in ensuring year-round production of crops by providing climatic conditions within the permissible limit irrespective of the weather conditions outside.

12. Application in Floriculture

The floriculture crops require highly controlled environments for growing valuable flowers. The greenhouse systems equipped with sensors can help in regulating temperature, humidity, light and root-zone

moisture through automatic systems of irrigation, ventilation and shading.

High-value floricultural crops like rose, gerbera, chrysanthemum, and others require highly controlled environment for achieving desired size of flowers, stem lengths, color, flowering period and flowering time. Automated systems can therefore improve production consistency and reduce labour requirements.

13. Applications in Nursery Production

The sensor-based technology can be highly valuable in nursery production because there is need to strictly regulate moisture content, temperature, humidity, and light in the seed germination and seedling development processes. Automation will prevent over or under-irrigation, and the environmental sensors will assist in maintaining proper conditions for seedling development.

Sensor-based technology ensures the cultivation of more uniform and strong planting materials since healthy seedlings are critical for good establishment and productivity of the transplants.

14. Benefits of Sensor-Based Smart Greenhouses

The sensor-based smart greenhouses technology comes with several possible benefits in the crop production process in the controlled environment. Constant monitoring results in provision of continuous information regarding the crop environment and prompt reaction to changes. Automated irrigation improves water usage, and the precision

fertigation ensures that the unnecessary nutrient is not applied.

There is also labor savings associated with automation of irrigation, ventilation, and environmental control. The improved environmental control ensures better crop growth, uniformity, quality, and productivity. There will be reduced crop losses through early identification of any environmental stress or disease conducive conditions.

The technology will ensure better record keeping and informed decision making. Information from previous cycles can be used to compare production cycles and improve future crop-management strategies.

CONCLUSION

Smart greenhouse technology using sensors has revolutionized protected agriculture by bringing about changes from traditional hand-operated operations to automation and precision in farming. The sensors monitor the temperature, relative humidity, light, carbon dioxide, soil moisture, electrical conductivity, and other crucial parameters while the controllers and actuators utilize the data for controlling watering, fertilization, ventilation, cooling, heating, and shading of the crops. It offers great possibilities for water and nutrients' utilization, labor-saving, improvement of crop uniformity and productivity, and high-quality production of horticultural products throughout the year. It can further be improved by linking with IoT, artificial intelligence, machine vision, and renewable energy.