Review Article

Application of IoT in protected cultivation: a Review

ABSTRACT

In step with the Food and Agriculture Organization of United Nations report food production is predicted to extend about 70 per cent in 2050 to fulfil the demand of food because the world's population will exceed nine billion by that time. In agriculture, improving crop yield is crucial to fulfil the swiftly growing demand of food for population intensification. There are a lot of factors to manage for crop yield, including temperature, humidity, light intensity, moisture and carbon dioxide concentration. Greenhouse farming is an 'all season garden' method of providing favourable environmental conditions to plants by growing them under a framed structure covered with a transparent material. These protected agriculture uses artificial techniques to create environmental conditions suitable for the growth plants, with automated controls. With the development of agricultural sensor, wireless communication, cloud computing, and machine learning, IoT technology has emerged and is gradually being promoted and applied in the protected agriculture field. The major components in IoT includes sensors, gateway, connectivity, cloud, analytics and user interface. Among these, sensors are the key component used for the continuous monitoring of greenhouse environment. There are different type of sensors used for monitoring each environmental factors. The physical layer, software, and sensors layer under data acquisition are linked wirelessly through standard communication protocols for transmitting data to a central base station for real-time or offline processing. Due to the importance of greenhouse climatic conditions and their effect on quantitative and qualitative crop yield, greenhouse climate simulation models are used, which includes climate modelling and crop growth models.

Keywords: greenhouse, internet of thing, sensors, climate simulation, crop growth model

1. Introduction

Food is the most essential requirement for sustenance of human life. In step with the Food and Agriculture Organization (FAO) of United Nations report in 2021, food production is predicted to extend about 70 per cent in 2050 to fulfil the demand of food because the world's population will exceed nine billion by that time. In order to fulfil the growing demand of food, improving the crop yield became a necessary step in agriculture (Kumar *et al*., 2017). Increment of crop productivity could be meet by predicting ecological circumstances (Krishnan *et al*., 2020). In addition to smaller land holdings, the practice of traditional farming could be one of the reasons behind lesser crop production and productivity.

Climate variability is considered to be one of the major problems within the agriculture sector as it results in alterations in production. There are a lot of factors to manage, including temperature, humidity, light intensity, moisture and carbon dioxide concentration (Jinu, *et al.*, 2016).

Obtaining real-time agricultural data for crop monitoring and production forecasting is a difficult task. Real-time information can be used into crop management and yield modelling. (Gaikwad, *et al*., 2021). Farmers can increase crop yield by using proper agrometeorological and weather parameter analyses (Jangam *et al*., 2018). Additionally, it can assist farmers in choosing the best fertilizers and herbicides (Ayaz *et al*., 2019; Elijah *et al*., 2018). These methods, which are also referred as precision farming, can lower the cost of input and increase the yield for farmers (Nabi *et al*., 2020).

Greenhouse farming is an 'all season garden' method of cultivating plants within a frame structure covered in a transparent material to provide them with favourable environmental conditions. These structures ensure an ideal temperature that is suited for growth of plants in all seasons due to controlled climatic conditions and it protects the crops from unwanted pests and diseases attacks.

Artificial techniques using automated controls have been installed in the protected agriculture for creating suitable environmental conditions for plant growth by changing Climate variables like daylight, temperature and humidity, thus, growers can manage each and every environmental factor much more easily and with less burden. Automated controls can be integrated into all parts of a greenhouse system to keep the environment attuned to a particular crop's needs without constant monitoring and adjustment. Having an automated greenhouse will help maintain an ideal growing environment by creating consistent and predictable cycles.

By reducing water, fertilizer, and energy consumption in closed-field environments, and at the same time increasing yields and profits, microclimate control and Fertigation practises within greenhouses have improved sustainability (Shamshiri *et al.*, 2018). Monitoring of environment conditions in modern agriculture is shifting to wireless and cloud-based systems from offline systems (Shamshiri *et al.*, 2020). There have been a variety of data acquisition platforms used to improve greenhouse production, both prototype and commercial

Internet of Things (IoT) technology has evolved and is progressively being promoted and utilised in the field of protected cultivation along with the advancement of agricultural sensors, wireless communication, cloud services, and machine learning techniques (Shi *et al.*, 2019). Mobile devices using wireless sensors and IoT devices can monitor and control the greenhouse environment in real-time via a secure internet connection. Electrical devices connect with a server via IoT and exchange information without the need for human intervention. IoT refers to technology that allows people and things to be connected anytime and anywhere, with any device and anyone, using any path/network (Nawandar, 2019). The definition of things in IoT is very wide and includes a variety of physical elements (Vashi *et al.*, 2017).

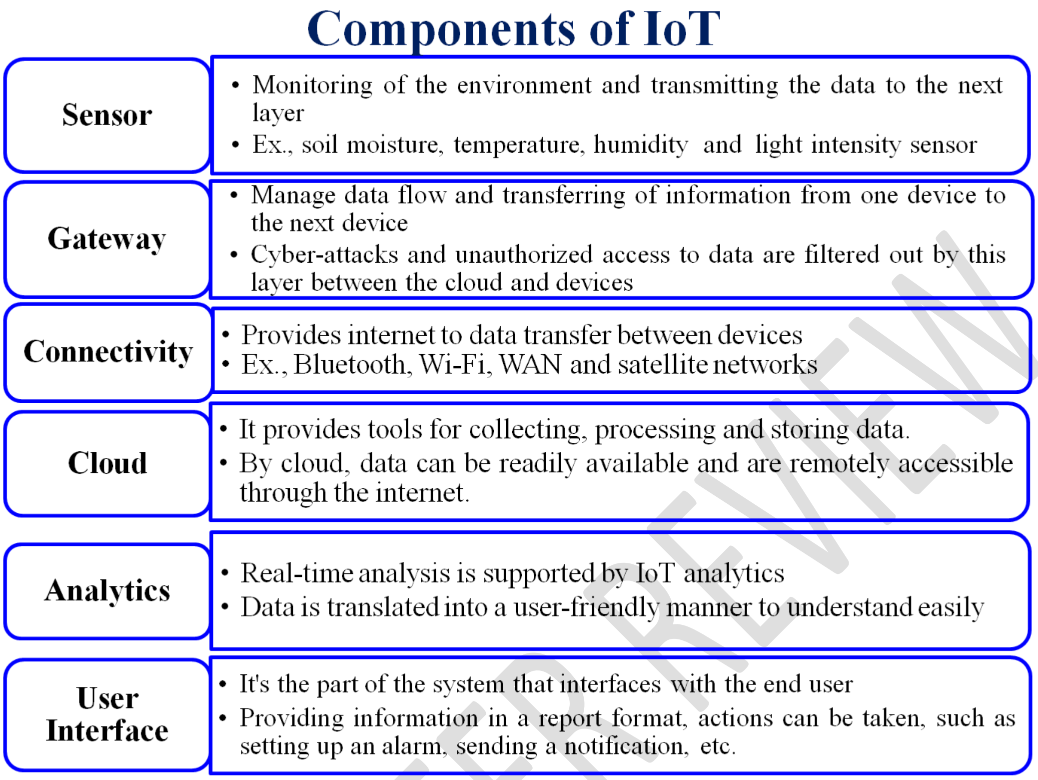
2. Internet of Things (IoT)

In 1999, Kevin Ashton coined the term Internet of Things (IoT). In his vision, computers would be used to organize and manage things in a world where everything has its own digital identity. According to Atlam *et al.*, (2018) IoT is defined by technology that enables for connections between people and things at anytime, anywhere, with anything, and with anyone, preferably using any path, network, and service. The internet refers to when two or more network are connected, it is called internet. The network consists of computer, devices, sensors, actuators, controllers etc.

The internet is used to connect devices via the IoT system. In addition to computers, mobile devices, and laptops, it also involves mechanical devices, sensors, home appliances, and vehicles. A device like this is designed to share data over the internet with other devices. IoT essentially offers a framework for things to communicate and work together.

2.1 Components of IoT

The main components in IoT are discussed below:



Components of IoT

Sensor	• Monitoring of the environment and transmitting the data to the next layer • Ex., soil moisture, temperature, humidity and light intensity sensor
Gateway	• Manage data flow and transferring of information from one device to the next device • Cyber-attacks and unauthorized access to data are filtered out by this layer between the cloud and devices
Connectivity	• Provides internet to data transfer between devices • Ex., Bluetooth, Wi-Fi, WAN and satellite networks
Cloud	• It provides tools for collecting, processing and storing data. • By cloud, data can be readily available and are remotely accessible through the internet.
Analytics	• Real-time analysis is supported by IoT analytics • Data is translated into a user-friendly manner to understand easily
User Interface	• It's the part of the system that interfaces with the end user • Providing information in a report format, actions can be taken, such as setting up an alarm, sending a notification, etc.

2.1.1Sensor

The IoT gadget is connected to the outside world or to people via the sensor layer. It transmits information to the cloud for additional processing when it detects changes. Monitoring of the environment and transmitting the data to the next layer is done by several sensors like moisture sensor, a temperature sensor, and a light intensity sensor.

2.1.2 Gateway

Using a gateway, you can manage data flow and transferring of information from one device to the next device. It encrypts the data going via the network and translates network protocols for devices. Cyber-attacks and unauthorized access to data are filtered out by this layer between the cloud and devices.

2.1.3 Connectivity

For analytics, it is necessary to upload sensor data to the cloud. For this data transfer between devices requires the internet as a medium. Therefore, all IoT devices must be online at all times. Several networks such as Bluetooth, Wi-Fi, WAN, and satellite networks make it easy to stay connected.

2.1.4 Cloud

Data from devices sent by IoT systems must be managed efficiently in order to produce meaningful outcomes. An IoT cloud is said to be advanced, high-performance server network that can process large amounts of data at high speed. It provides tools for collecting, processing and storing data. By cloud, data can be readily available and are remotely accessible through the internet. Additionally, it also provides a platform for the next analytics layer.

2.1.5 Analytics

Raw data is transformed into meaningful information by analytics. Real-time analysis is supported by IoT analytics, which captures changes in real time. Following that, data is translated into a user-friendly manner to understand easily. As a result, trends in the report can be analysed by the end users, thereby forecasting the market and plan in advance for a effective implementation of their ideas.

2.1.6 User Interface

The visible, tangible part of IoT systems is the user interface. Basically, it's the part of the system that interfaces with the end user. In addition to providing information in a report format, actions can be taken, such as setting up an alarm, sending a notification, etc. Some actions can be chosen by the user. Because of this, designing an intuitive interface that can be used easily and without extensive training is important. The easier the user interface, the product is more successful

2.2 Greenhouse monitoring and controlling using IoT

In greenhouse cultivation, the climatic conditions have a significant impact on crop production. The most significant environmental factors (Table 1, Hakkim *et al.*, 2014) which affect the quality and optimal productivity for the growth of plants are temperature, humidity, light intensity, moisture, and CO_2 concentration (Bai *et al.*, 2018, Carpenter *et al.*, 2019). The relevant information related to the individual effects of these factors on maximum crop production is obtained from continuous monitoring. Table 2 describes the various climate control methods used in greenhouses. Sensors are key components for the monitoring of greenhouse systems. As the name implies, a sensor is any electronic instrument or device that measures the characteristics of the environment and sends the data as an electrical signal to the main automation computer for interpretation and decision making. At the same time, data regarding these climatic parameters are sent to the IoT module. Fig.1 shows the block diagram of greenhouse monitoring and controlling using IoT.

Table 1 Important climatic factors in relation with plant growth

Sl. No.	**Climate factors**	**Significance**		**Desirable level in polyhouse**
1.	Radiation/Light	Photosynthesis, Photomorphogenesis Photoperiodism	:	50000 to 60000 lux
2.	Temperature	Cell division & elongation Respiration, photosynthesis Water uptake, transpiration	:	18 to 25°C
3.	Relative Humidity	Quality of plants	:	60 to 80 %
4.	CO_2	Photosynthesis	:	350 to 1000 ppm
5.	Air movement/wind	Influences temperature, humidity & CO_2, structural stability	:	Inflow: outflow ratio should be 1:1 per hour

Table 2 Various climate control methods used in greenhouse

Sl. No.	Parameters	To control	Equipment
1	Radiation/Light	Increase	Incandescent lamp, fluorescent lamps, high intensity discharge lamps
		Decrease	Shade nets, black out screens
2	Temperature	Increase	Heaters, steam heating
		Decrease	Misters, foggers, roof sprinklers
		Shading	Shade nets/ screens
		Ventilation	Vents, exhaust fans
3	Relative Humidity	Increase	Humidifiers, foggers, misters
		Decrease	Heaters, vents, dehumidifiers
4	CO_2	CO_2 enrichment	CO_2 burners, pure CO_2

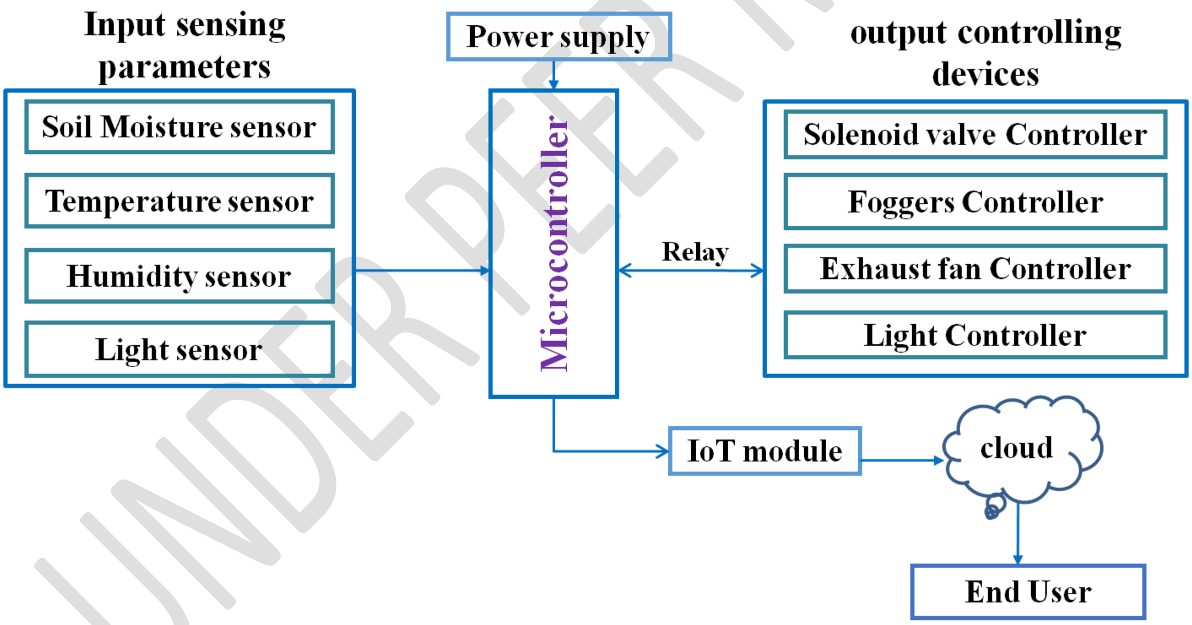


Fig.1. Block diagram of greenhouse monitoring and controlling using IoT.

2.2.1 Types of Sensors

For controlling the environmental conditions inside the greenhouse according to the plant requirement, different sensors are used that measures the parameters and are discussed below:

Table 3 Types of Sensors

Sensors			
Soil moisture Sensors	**Temperature Sensors**	**Humidity Sensors**	**Light Sensors**
Capacitive type	Thermostats	Capacitive	Pyrometers
Resistive type	Thermocouples	Resistive	PAR Sensors
		Thermal	Light Dependent Resistor
		Conductive	

2.2.1.1 Temperature Sensors

Growing crops in greenhouses is advantageous due to their ability to provide ideal temperatures for plant growth and development. In many production systems, air temperature measurement and control are common practices since it is one of the primary factors affecting plant temperature. Temperature thermostats/sensors are usually mounted in aspirated boxes suspended near the crop in order to measure air temperature. Furthermore, root zone temperature (substrate temperature) also affects plant health. Thermocouples (sensors) are typically used in conjunction with loggers or loggers which contain sensors. This consists of two wires of two different metals that are twisted and brazed or held together. By monitoring plant temperature, one can better control the environment for growth and control disease outbreaks. The rate of plant development are controlled by the plant temperature. For instance, the temperature has a direct impact on elongating stems, flower buds, leaf unfolding, and flower bud development.

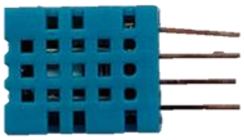


Fig.2. Temperature and humidity sensors

2.2.1.2 Soil Moisture Sensor

The two copper leads act as the sensor probes. A sample soil's moisture content is tested by immersing them in it. The conductivity of soil is directly proportional to the amount of soil moisture. As the soil moisture increases, that forms a conductive path between two sensor probes to allow current flowing through by forming a closed path (Vimal and Shivaprakasha, 2018).

In order to calculate Volumetric Water Content (VWC), majority of soil moisture sensors rely on analog technology (non-rust capacitive hygrometers) which measures the dielectric constant of the media. Low salt sensitivity and low power consumption are possessed by sensors with these characteristics. For real-time monitoring, they can be directly connected to IoT boards or through interfaces with an operating temperature range from -40 to 50 °C (Spelman *et al.*, 2013).

Fig.3. Soil moisture sensors

2.2.1.3 Light Sensor

The light sensor is extremely sensitive in visible light range. It displays the digital values that correspond to the light intensity during low natural light.

Pyrometers: Pyrometers are most suitable for greenhouse control as it measures global radiation (entire spectrum of light). Generally, it is measured with a pyrometer in watts per square meter ($W \cdot m^{-2}$). The common unit is watts per square meter per second.

PAR Sensors:

PAR or quantum sensors measure Photosynthetically Active Radiation (PAR) in the 400 to 700 nm wave band. The unit of measurement is micromoles per square meter per second ($\mu mol \cdot m^{-2} \cdot s^{-1}$ or $mmol \cdot m^{-2} \cdot day^{-1}$). These sensors are mainly used in horticulture research applications, laboratory applications and light studies. In commercial greenhouses, in order to position new lighting systems, these sensors are used to check the uniformity and intensity of PAR by comparing the values at various points in the plant canopy, and under screens.

Light Dependent Resistor (LDR) Sensors:

Light level sensor, also known as a Light Dependent Resistor (LDR) that is an active sensor, made up of high-performance, fast-responding, and highly resistant semiconductor material. It works on both mode analog as well as digital. It gives output in both mode analog and digital. In relates to the receiving luminosity (light) on the sensitive surface of the component, it decreases resistance (it exhibits photoconductivity). Photo-resistor resistance can range from several megaohms (MΩ) in the dark to only a few hundred ohms in the light. This sensor's raw output data needs to be calibrated before being used for specific interpretations. For this sensor, the operating temperature is from -40 to 75℃ with response time of 2 to 50 ms.

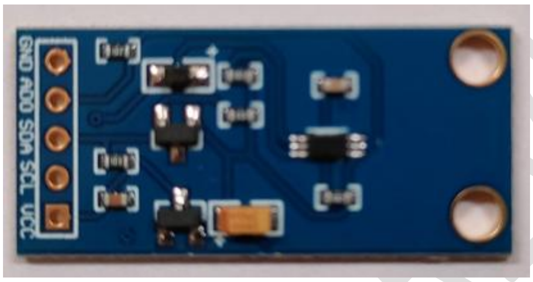


Fig.4. Light sensor

2.2.1.4 Humidity Sensor

The vapours in the air are sensed by this sensor and display the respective values of change in RH (Relative Humidity) of the surroundings. There are three common types of humidity sensors: capacitive, resistive, and Thermal conductive. Capacitive sensors measure moisture levels (5 to 95 per cent, ±2 per cent accuracy with response time from 30 to 60 s) using a humidity-dependent condenser and are mostly used in industrial and commercial environments. Resistance sensors are able to measure the change in electrical resistance in devices such as conductive polymers and treated substrates and are suitable for the residential and commercial applications. These sensors will measure soil moisture in the range of 10 to 90 per cent having ±2 per cent accuracy with response time from 10 to 30 s. Thermo conductive sensors perform well in high-temperature environments. In order to measure humidity, they calibrate the difference between the thermal conductivity of dry air and of moist air. These sensors will measure soil moisture in the range of 15to <100 per cent having an accuracy of ±5 per cent with response time from 30 to 50 s (Rovetti *et al.*, 2011).

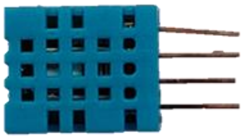


Fig.5. Humidity sensors

2.2.1.5 Carbon Dioxide Sensors

In spite of the fact that carbon dioxide (CO_2) is key to plant photosynthesis, measurements of CO_2 concentration are often ignored. Very low carbon dioxide concentration is often found to be in tightly enclosed greenhouse on cold winter morning due to plant photosynthesis. In order to optimize plant production, it is always necessary to at least monitor CO_2. The greenhouse CO_2 sensor mainly detects CO_2 using the Non-Dispersive InfraRed (NDIR) principle (by measuring the absorption of an infrared light source via a certain air sample). A good air permeability property provides the sensor with resistance to high humidity environments as well as high selectivity, high measurement accuracy, long life and no oxygen dependence. Most commonly used sensor for measuring carbon dioxide concentration is an InfraRed Gas Analyzer (IRGA) (Fig.7). This sensor is having the range from 0 to 3000 ppm with an accuracy of ±30ppm and response time <4 s (Araujo *et al.*, 2020).

Source: https://iifsr.icar.gov.in/irga

Fig.6. InfraRed Gas Analyzer

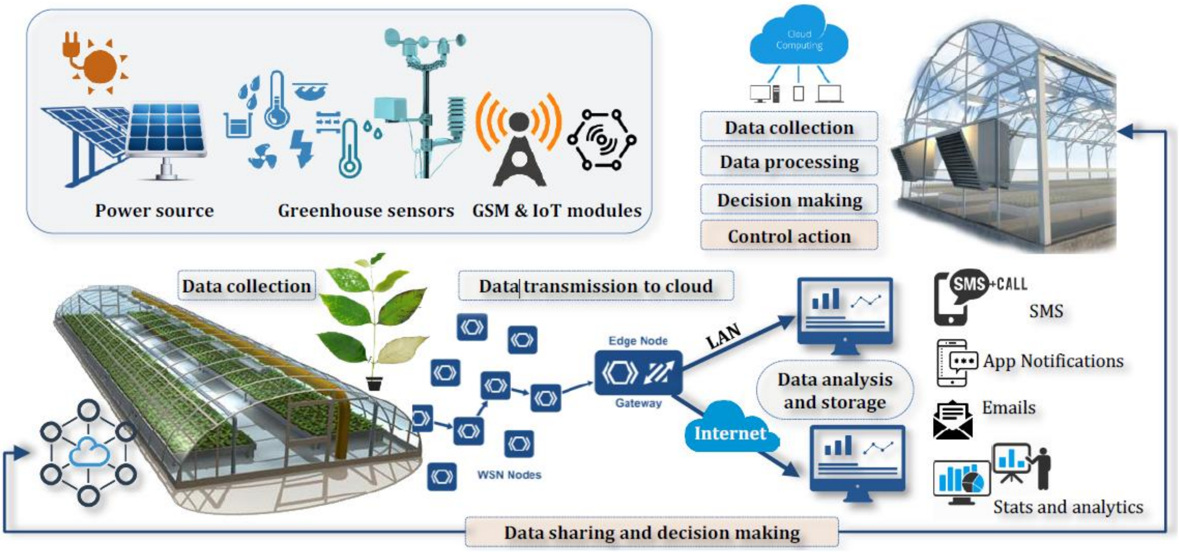
A custom-designed sensor probe may be necessary for some applications in greenhouse production and research, in addition to the sensors mentioned above. When a greenhouse is misted or fogged, measurement of the solution droplet deposition on the plants is necessary. To avoid condensation in certain hours inside greenhouse, leaf wetness can be used as a reference measurement. Measuring leaf surface wetness is essential to determining the effectiveness of chemical depletion in large commercial greenhouses. As shown in Figure 8, the ADP-AgroTech leaf wetness sensor model ADP-LWS2020 is designed to mimic the shape of actual leaves with different shapes, and to convert the leaf surface moisture into an analog signal. These sensors are optimized to neglect the noise thereby giving high resolution output under extreme greenhouse conditions. These sensors work on the dielectric principle and it can be used for greenhouse studies like early warnings about fungus and insect attacksand for scheduling irrigation.

Source: www.AdaptiveAgroTech.com

Fig.7. ADP-AgroTech leaf wetness sensor (model ADP-LWS2020) with different leaf shapes based on capacitive method for determining leaf surface moisture and greenhouse condensation

2.3 IoT sensing and data sharing in greenhouse production

For disease prevention, commercial greenhouses must be enabled with continuous sensors, communication between devices, and data sharing with greenhouse management systems (Ferentinos *et al.*, 2017). Mildew fungi, for example, can cause yield losses up to 50 percent in greenhouses (Shamshiri *et al.*, 2018). Shamshiri *et al.* (2017) showed that heavy rainfall, fog, and extreme air temperatures can contribute to the advancement of fungal growth on the leaves in hot and humid tropical areas. Combining sensor data with mathematical models can provide growers to take necessary actions by predicting the outbreak of diseases. The Figure 9 illustrates the main elements of an IoT-based data collection and data sharing system. Using this framework, growers can evaluate microclimate parameters before actual cultivation based on different greenhouse designs and covering materials. With this scheme, the physical layer, software, and sensors layer are connected wirelessly for data transmission to a central base station following standard communication protocols for real-time or offline analysis. For continuous greenhouse monitoring during all seasons, this approach must exhibit precision accuracy, connection reliability within the coverage, and should have low power consumption. The physical internal and external conditions of the greenhouse environment can also influence the functional properties of a wireless monitoring system.



Source: www.AdaptiveAgroTech.com.

Fig.8. General components of a greenhouse environmental monitoring based in wireless sensor network and IoT concept

2.3.1 Microcontroller

The microcontroller is considered as the heart of IoT system. Digitized parameters of each sensor used in respective IoT system are constantly monitored and verifies them with the predefined threshold values. If the sensor is not in terms with the threshold values, it activates the actuators to perform a controlled operation. There are different range of microcontroller are available from the simple 4-bit, 8-bit or 16-bit processors to more complex 32-bit or 64-bit. Some of the most commonly used microcontrollers in greenhouse are Raspberry pi, Arduino, ESP32, etc.

Fig.9. Microcontroller

2.3.2 IoT connectivity boards and modular accessories

Multi-channel connectivity boards with WiFi and LoRa antennas which are provided with a modular design for easy interfacing with sensor probes. In addition to expanding existing wireless networks with new sensing capability, these boards are custom-designed to ensure minimal effort is required. The same applies to defective sensor probes, which can be easily replaced when required in order to make the sensor network as low-maintenance as possible. In Fig.10, connectivity boards are shown with all the electronics and sockets necessary for wireless monitoring of greenhouse environments. By default, at every 10 seconds, the boards are programmed to read and record measurements, which can be adjusted according to the grower's needs. Data is then stored on a mini-SD card or transferred to a secure cloud database via a WiFi connection.

Fig.10. GSM module

In order to withstand severe environmental conditions such as exposure to sunlight, dust, high humidity, and insects’ attacks, sealed waterproof ABS enclosures are used to house the wireless sensor, controller boards, and also the other electronic components and modules. For greenhouse application, it is very important that all enclosures are suitable for all types of environments, corrosion resistance, good sealing performance, high-quality ABS flame retardant material, anti-UV and anti-aging, and have long life.

3. Greenhouse simulation models

Using greenhouse simulation models, one can analyze the interactions between greenhouse plants and climate, including the shape of the structure, characteristics of the cover, the climate control equipment, and the surrounding weather conditions (Luo *et al.*, 2005). Analyzing the greenhouse climate becomes a complete task because of the enormous variety of boundary conditions and design elements. Simulation tools makes it possible to take all of these characteristics into account thus they become an indispensable support for greenhouse climate studies (Piscia,2012) Therefore, such simulation model can serve for the optimization of greenhouse design, climate control, and crop management. Growing plants is a complex process that is influenced by numerous factors, including soil, plants, and climate. Crop growth models play a crucial role in optimizing crop management (Lin *et al.,* 2019). Plant modelers working under the Functional-Structural Plant Modelling (FSPM) community are developing models to understand the biological processes in plant growth. Recent advances in computer technology have enabled scientists to construct three-dimensional models of plants to understand these biological processes, as well as the interactions between them. It has been considered how the vegetation interacts with its environment in three dimensions. With the Internet of Things and cloud computing, climate models and crop growth models have been developed, resulting in digital twin greenhouses being studied.

3.1 Climate modelling in greenhouse

There are two categories of dynamic models in the greenhouse climate modelling: mechanistic and black-box models (López-Cruz *et al.,* 2018). Models that are mechanical describe the system being simulated by knowing the processes that are happening (Watt, 2013). On the other hand, the black-box models are used for greenhouse applications involving control, optimization, and design. In mechanistic models, physical equations are used to determine knowledge-based decision support for climate control actions (Hemming *et al*., 2020). Consequently, they allow a quantitative evaluation of the system through transparent mechanistic models, allowing optimization algorithms and they are physically interpretable. Black box models permit statistical description based on outputs, given inputs within a specific range and is not necessary to determine the value of each parameter for black box models. This model uses empirical approach by taking only the data obtained from direct measurements. For climate control purposes, these models can be very helpful to estimate the environment change inside the greenhouse (Mohammadi *et al.,* 2018). Bot developed one of the first mechanistic dynamic models of greenhouse climate in 1983 (Bot,1983), while Van Henten developed the first model of greenhouse climate modelling for optimal control purposes in 1994.

3.2 Crop growth model

The crop growth model plays a crucial role in the optimization of cultivation management (Lin *et al.,* 2019). A crop growth simulation model is a quantitative tool based on mathematical relationships and scientific principles which evaluates the impact of climate, soil, water, and crop management factors on crop growth.

Models of growth can be classified into two categories: descriptive and explanatory. Using regression analysis of the crop data, a descriptive model is developed to determine the relationship between the research factors. Based upon the principle of dynamics, the explanatory model explains the relationship between environmental factors, crop growth and management factors and yield formation.

For greenhouse crops, a number of explanatory models exist, among them TOMGRO and HORTISIM for general crops. These models share a common weakness in that their specific parameters for the climate condition and greenhouse design from which they were derived. Furthermore, due to the complex interactions between greenhouse elements and the crop itself, it is often impossible to predict the microclimate effects on the final yield accurately with the same model parameters.

3.2.1 Functional–structural plant (FSP) modelling

Models of FSP simulate growth and morphology of individual plants as well as their interactions with the environment, from which complex properties of plant communities are derived. For over two decades, these models have been used to understand the complex interactions between plant physiology and underlying biological processes driving plant growth.

FSP models can simulate the three-dimensional structure of plants, which are influenced by biological and non-biological factors of vegetation (Light, temperature, fungi, insects, etc.). A three-dimensional model can consider how leaf size, angle, and optical properties affect light retention and scattering on leaf surfaces. The information obtained can be used to characterize photomorphogenesis, photosynthesis, and for the overall plant growth and development. FSP modelling is able to relate the behavior of a single plant to the performance of the entire canopy. An illustration of FSP modelling, which can be scaled from gene integration to community integration (Fig.11).

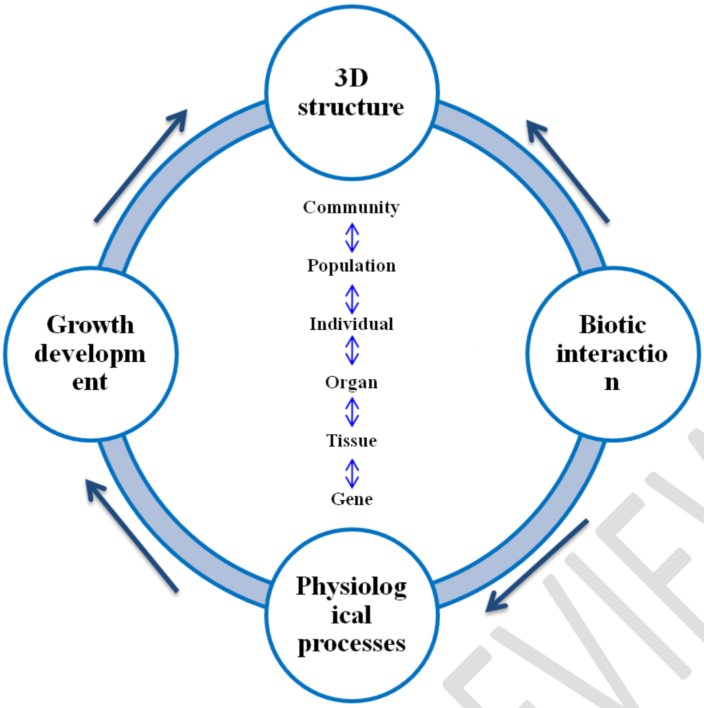


Fig.1. Conceptual diagram of functional–structural plant (FSP) modelling (Evers et al.,2018)

4. Conclusion

The emergence and the consequent popularity of IoT in agriculture not only improves production efficiency, reduce the heavy reliance on labour in traditional agricultural production, but also opens up a wide range of opportunities for new types of agriculture businesses. In order to interpret crop growth environments, traditional wired sensors and offline data acquisition boards, which only exhibit raw data as output, are being replaced by real-time IoT sensors and cloud-based data collection platforms. Using advanced sensors, it is possible to remotely monitor soil nutritional content, water/humidity and temperature, as well as real-time plant physiology (vegetative index, nutritional requirements).

5. Future Prospects

There is hope for the future of IoT with the emergence of graphene (a material with high strength, light weight, and flexibility), microfluidic chips and high-precision rRNA biosensors. However, it remains unclear whether future technologies would help to lower the cost of sensors with higher functionality. At present, the inclusion of such capabilities such as accurate and precise measurements, long-term deployment etc. in sensors cost 1,000 USD or more. To eliminate the capital and infrastructural barriers, the emerging technologies such as the LEO constellation would help provide global broadband internet coverage in remote errors for the mass IoT adoption in commercial agriculture.

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