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Review

Sensors and smart farming using IoT: A review on potential applications in horticultural crops

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ABSTRACT

Horticulture farming is a subset of agriculture, contributing approximately 30% of the agricultural GDP in India. The nutritional benefits of horticultural crops such as fruits, vegetables, and mushrooms play an important role in daily life. With the ever-increasing demand for food, the horticultural industry faces new challenges that require innovative and sustainable solutions. This has led to a significant shift towards technology-driven solutions to address the challenges of a growing population in a sustainable way. The Internet of Things (IoT), a promising technology in smart farming, greatly helps in real-time monitoring of plant growth status and facilitates faster decisions under challenging circumstances. Smart farming in horticultural crops relies on a range of components including sensors, actuators, microcontrollers, and cloud storage for the effective implementation of IoT. These components work together to collect and store data, which can be utilized to optimize the allocation of input resources. This review discusses how components of smart farming can improve resource management, crop yields, and the quality of production of horticultural crops, along with its applications and development in this area.

Keywords: Horticulture, internet of things (IoT), IoT data analytics, sensors

INTROUCTION

Artificial intelligence (AI) has become the buzzword of this century and has created an enormous impact. AI, Internet of Things (IoT) and machine learning algorithms have a great relevance in agriculture and play a great role in solving many traditional farming problems. Field sensors for soil moisture monitoring and weather monitoring are connected using wireless sensor networks. Such platforms help to assess and control the field variables effectively (Chen et al. 2014). Machine learning and computer vision techniques helped in the validation of taxonomic identification and the development of reference databases (Høye et al., 2021). The IoTs has the potential to transform the horticulture industry by enabling the collection and exchange of real-time data from a wide range of sensors, devices, and systems. An innovative irrigation control system was created utilizing IoT technology, designed to efficiently provide water to plants based on their specific requirements (Al-Zahrani & Al-Baity, 2019). Leveraging an open-source crop management platform, the system integrates crop management and plant phenotyping to enable precise monitoring and efficient optimization of water resources (Reynolds et al., 2019). Utilization of IoT sensors to monitor water stress in horticultural crops for better understanding of the interaction effect between various factors on crop growth, development and yield is becoming essential. Using image-derived digital features, moisture stress tolerance of nine tomato genotypes was quantified under sensor-enabled greenhouse conditions with the assistance of high-throughput imaging (Laxman et al., 2022). IoT-connected smart farm systems optimize water usage by collecting data on soil moisture and weather conditions, enabling farmers to apply the precise water required for their crops, thereby reducing water wastage and improving crop yields. This paper aims to provide a comprehensive review of the integration and applications of the Internet of Things (IoT) in horticultural crops, highlighting its potential to enhance precision farming, resource optimization, and sustainability.

Components of IoT

The word Internet of Things was coined by Kevin Ashton in 1999, representing data collection from

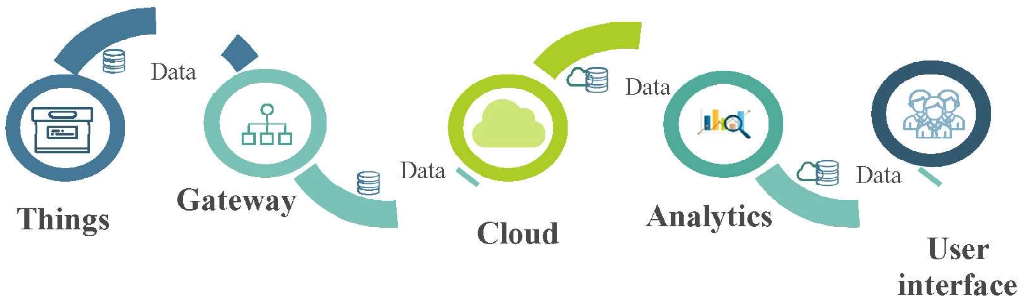

Fig. 1 : Components of IoT architecture in smart farming

"things". International Telecommunication Union ITU-T Y.2060 prescribes the following definitions to attain a clear perception of a "device" and a "thing" in an IoT. A device is a piece of equipment with the essential abilities to communicate with other devices, sense an object or environmental factors, actuation, data capture and storage. "Things" includes everything from temperature sensors, cameras, smartphones, buses and almost everything we can think of. The main components of IoT are Things or sensors to collect information. With the help of Gateways, the collected information can be sent to the cloud platforms. Data stored in the cloud platform are being analyzed using machine learning or deep learning algorithms to get insights and inferences about the information collected. A user interface is created to monitor all these functionalities, to receive the output and can be used for better decisions.

Sensors and their role in data collection

Sensors are devices that convert physical parameters into electrical impulses, which a controller can read and process. Sensors are mainly used to collect environmental data, monitor and analyze for further processing. The varied responses from plants towards environment can be captured with the help of diverse sensors to obtain data that aids in the real-time monitoring of plants. Some of the important sensors required for crop monitoring are temperature, humidity, soil moisture, nutrients, CO_2, infrared, light, and pest and disease management sensors. A decision-making system grounded in IoT data collection for precision agriculture utilized a range of temperature and humidity sensors, including DHT11, LM35, SHT 75, and SHT 3x –DIS, which were evaluated based on their precision, energy efficiency, and field

Table 1 : List of commonly used sensors in smart horticulture

Sensor type	Model	Significant Features
Temperature and Humidity sensors (Dewi et al., 2019)	DHT11	Low cost, suitable for simple applications
	LM35	High accuracy, no need for external calibration
	SHT 75	High precision and stable
	SHT 3x	Low power consumption and energy-efficient
Soil moisture sensors (Datta et al., 2018)	TDR 315	Ideal for precise soil moisture measurement
	CS655	Reliable and durable in demanding field applications
	GS1	Resists water intrusion and works in harsh environmental conditions
	SM100	Cost-effective and easier installation
	CropX	Records moisture, temperature and electrical conductivity
	SEN0114	Equipped with an Immersion Gold surface finish, which offers excellent oxidation resistance and durability,
NPK sensor (Smolka et al., 2017)	RS485	detecting small changes in the concentration of N,P, and K in the soil, with a resolution as fine as 1 milligram per kilogram (mg/kg)
CO_2 sensor (Aziz et al. 2019)	MG811	High sensitivity and stability for CO2 detection, with both analog and digital outputs, making it ideal for applications in greenhouses
PIR motion sensor (Saranya et al., 2019)	HC-SR501	Offers a broad detection range of 3 to 7 meters, adjustable motion-sensing time from 3 seconds to 5 minutes.

reliability under varying environmental conditions (Dewi et al., 2019). Similarly, five different electromagnetic soil moisture sensors (TDR315, CS655, GS1, SM100, and CropX) were systematically evaluated under low and high salinity conditions (Datta et al., 2018). The TDR315 sensor exhibited precise soil moisture measurement capabilities, while the CS655 proved to be highly durable in demanding field applications. The SM100 offered a cost-effective and easily deployable solution, whereas the CropX sensor provided comprehensive data on moisture, temperature, and electrical conductivity, enhancing its applicability for multi-variable monitoring in precision agriculture. The application of different types of sensors are presented in Table 1.

Microcontroller boards: Brain of IoT system

Microcontrollers are self-contained computers hosted on a chip. This microchip has a control unit that can connect with things in the IoT world. Some of the widely used microcontrollers in agriculture for monitoring and irrigation systems are Arudino uno, Raspberry pi, Beaglebone black, STM32 and ESP32. The intelligent maintenance of potted horticultural plants has been developed using the STM32 microcontroller, which can handle complex algorithms and conserve energy (Ren et al., 2020). ESP32 microcontroller with a built-in wifi module was used to develop Pytotron- a growth chamber for growing horticultural crops using IoT sensors (Abdelouhahid et al., 2020). Different wireless communication technologies and its features utilized in smart farms are presented in Table 2.

The big 6 cloud service providers are Amazon Web Services (AWS), Digital Ocean, Google Cloud, IBM Watson cloud, Microsoft Azure and Oracle Cloud.

Micro-climatic conditions in horticultural crops were monitored through IoT sensor devices and the information was maintained in the cloud database (Deliana et al., 2022). Stored data can be analyzed and visualized, and decisions can be made available to farmers through mobile applications. GrowFruit, an IoT-based radial growth-rate measurement device for fruit, was developed to measure perimeter changes in the fruit more precisely, and the data are sent to the cloud to analyze the change in growth rate (Sengupta et al., 2021). Cloud platforms eliminate the need for expensive computer equipment, software, people, infrastructure, and resources as well as their upkeep. All agricultural data may be consolidated on the cloud for future analysis and insights.

Integration of machine learning in IoT data analytics

The IoT system developed (Postolache et al., 2022) for horticultural crops estimated N, P, K, and pH levels using in situ soil nutrient sensors. A correlation matrix was derived from the data collected using sensors, and it was observed that there was a strong correlation between the data on soil moisture, electric conductivity, and concentrations of N, P, and K before precipitation and slight weakness after precipitation. A multimodal dataset was created using IoT-based environmental data along with RGB image datasets were analysed using convolutional neural network (CNN) and long short-term memory (LSTM) to estimate the water status and to deliver irrigation strategies (Elsherbiny et. al., 2022). In sensor-based greenhouse conditions, (Laxman et al., 2018), utilized machine learning algorithm to estimate the digital biomass of tomato plants across four different growth stages Data analytics in IoT data of horticultural crops helps in optimizing irrigation schedules, identifying early signs of plant diseases or pest infestations, and predicting crop yields. This empowers to make timely interventions, conserve resources, enhance productivity, and ensure sustainable farming practices (Fig. 2).

Applications of IoT in horticultural crops

Crop monitoring is an important application of IoT in horticulture. Sensors and cameras can be used to monitor crops for signs of pests and alert farmers to take action as needed. This can help to reduce the need for chemical pesticides and improve crop health. Acoustic and ultrasonic sensors can identify the area of infestation by capturing the noise and could gather information on feeding patterns using ultrasonic signals (Gogoi et al., 2022; Nayagam et al., 2023).

In addition to these applications, IoT can enable advanced supply chain management in the horticulture sector. Sensors and tracking systems can be used to track produce from farm to market, ensuring that it is handled properly and delivered fresh. This can assist in increasing the efficiency and transparency of the supply chain, and improve the overall sustainability

Table 2 : Different wireless communication technologies and its features utilized in smart farms

Feature	Near field communication (NFC)	BLE (Bluetooth Low Energy)	Wi-Fi (Wireless Fidelity)	NB- IoT (Narrow Band)	RFID (Radio Frequency Identification)	Zigbee	LoRA (Long Range)
Network type	Point to point	WPAN (Wireless Personal Area Network)	WLAN (Wireless Local Area Network)	LPWA (Low Power Wide Area)	Point to point	WPAN (Wireless Personal Area Network)	LPWAN (Low-power Wide Area Network)
Technology	Interacting electromagnetic radio technology	Radio technology	Radio transmission	Low-power Radio transmission	Radio frequency	Radio waves	Radio frequency signals
Communication direction	Bidirectional	Bidirectional	Bidirectional	Bidirectional	Unidirectional	Bidirectional	Bidirectional
Frequency	13.56 MHz	2.4 GHz	2.4 GHz or 5 GHz	650- 2000 MHz	125 KHz, 134 KHz (LF), 13.56 MHz (HF) and 860 to 956 MHz (UHF)	2.4 GHz	sub-gigahertz frequency band, typically between 868 MHz and 915 MHz
Range	< 10 cm	10 to 100 meters	Up to 50 meters	1-10 kilometres	1meter (LF), 0.5 – 6 meters (HF), 12 meters (UHF)	10-100 meters (indoor), approx. 300 meters (outdoor)	5- 20 kilometres
Data rate	Up to 424 Kbits/sec	2 to 3 Mbps	11 Mbps to 3 Gbps	200-250 Kbps	< 10 Kbps (LF), 400 Kbps (HF),	20- 40 Kbps	Approx. 50 Kbps
Network Topologies	Point	Mesh and star	Star, Tree, Point to point	Star	Mesh	Star, Tree, Mesh	Star
Advantages	Highly secured, less power consumption	Can transfer audio, video, text data, highly compatible with devices	High-speed connectivity, cost effective	Very less power consumption, enhanced security	Contact less operation, increased accuracy and security	Support thousands of nodes, suitable for low power devices	Long range, low power-can run on batteries for years
Limitations	Slower connectivity, limited range	Slow transfer speed, less security	Lower range, subject to interference from other electronic devices	Limited data transfer rate, limited number of connected devices	Expensive, limited read range	Low transmission rate, less security	Limited network size, low data rate
Agricultural applications	Agricultural process management, farm product management, and value-added services (Wan et al., 2019)	Light and temperature sensors employing Bluetooth communication protocol in greenhouse cultivation (Taşkın et al., 2018)	Battery free wireless monitor sensor for fruit monitoring (Xiao et al., 2022)	Farmland Intelligent Information Collection System Based on NB-IoT (Zhang et al. 2018)	Sugarcane growth monitoring system was developed using RFID (Biqing et al., 2018)	A 3-layered architecture is designed using zigbee for agriculture field automation and digitization (Choudhury et al., 2022)	Lora based soil fertility predicting system (Aarthi et al., 2023)

*LF: low frequency, HF: high frequency, UHF: ultra-high frequency

of horticultural operations. In Australia, the Horticulture Supply Chain Analytics (HSCA) framework developed for banana, turned out as an autonomous decision support system for farmers who do not have resources to monitor and gather information (Keates, 2023). The IoT and agricultural data analysis for smart farming was developed (Muangprathub et al., 2019) and broadly discusses the application of IoT and agricultural data analysis based on IoT devices. A micro-climate monitoring system, built upon IoT principles, was designed for the enhancement of horticultural practices in Indonesia (Kaburuan et al., 2019). With the help of soil moisture sensors, an IoT-based automatic irrigation system was developed (Pramanik et al., 2021) for basin irrigation systems and can be used in upscaling of automated water distribution networks in canal-based irrigation systems. Climate and soil moisture data have been collected and monitored by developing a web application for automated irrigation based on the evapotranspiration calculated (Soler Méndez et al., 2022). All these systems offers the advantage of closely monitoring plants' progress across different stages, right from the planting phase to the eventual

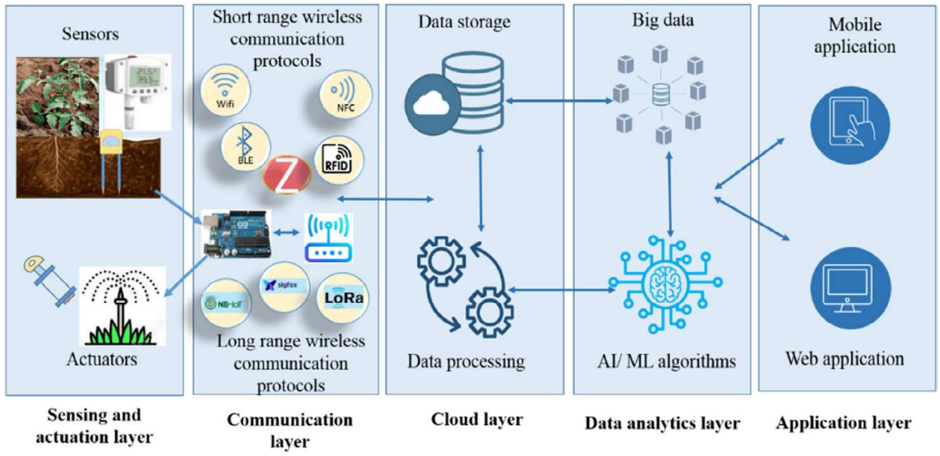

Fig. 2 : Conceptual data and control flow diagram of IoT in smart horticulture

harvest. Moreover, the data collected through this monitoring system will serve a dual purpose: enabling the development of a machine learning-based technology aimed at automating micro-climate control for horticulture and providing valuable insights for refining agricultural techniques. The potential IoT applications and implementation in horticultural crops are presented in Table 3.

Economic viability of IoT in horticulture

The economic viability of utilizing IoT in horticulture is increasingly recognized as a game-changer in modern farming practices. By enabling precise monitoring and control over key agricultural processes, IoT systems reduce resource wastage, optimize input usage, and significantly enhance crop yields. Palconit et al. (2020) demonstrate that IoT-enabled precision irrigation systems can reduce water consumption by 40% for tomatoes and 47% for eggplants, compared to traditional irrigation methods. This reduction in water use not only lowers operational costs but also contributes to more sustainable farming practices. An affordable, custom-developed IoT framework was implemented to monitor the growth of okra, leading to a significant enhancement in crop yield. This implementation resulted in a 10% increase in yield, showcasing the framework's effectiveness in optimizing agricultural practices through precise monitoring and timely interventions (Choudhury et al., 2019). These studies highlight the potential of IoT as a valuable investment in the horticulture sector, particularly in areas where water scarcity and the need for efficient resource management are critical concerns. The practical benefits of IoT-based precision monitoring systems for horticultural crops are exemplified on cabbage and capsicum (Mittal et al., 2018). The implementation of the IoT framework resulted in a 20% reduction in agricultural input costs, primarily through the precise monitoring and management of microclimatic and soil conditions, enabling more efficient resource utilization and improved cultivation practices. The system also resulted in a significant improvement in crop yields, with a 10% increase in capsicum and a 25% increase in cabbage, compared to traditional farming practices. IoT in horticulture is becoming an indispensable tool for boosting both sustainability and profitability in modern farming, particularly in regions where resource efficiency is critical.

Challenges and strategies for IoT adoption

Infrastructure and connectivity

In many agricultural regions, the deployment and operation of IoT systems are challenged by inadequate infrastructure, such as unstable internet connectivity and inconsistent electricity supplies. These limitations impede real-time data transmission and effective system monitoring, making it difficult to fully utilize the potential of IoT technologies in these areas.

To address these challenges, it's important to improve rural infrastructure by expanding network coverage and ensuring reliable energy solutions, such as solar power, for IoT devices in remote areas.

Cost

The cost of deploying IoT systems, including both hardware (sensors, devices, infrastructure) and software (development, maintenance, subscription

Table 3 : Diverse IoT implementation in horticultural crops

Crop	Focus	Parameters	Remarks	Reference
Vegetables				
Chilli	IoT-powered pest management system	Light spectrum, chlorophyll content, pest count	Green light spectrum attracted the most pests, while violet light enhanced chlorophyll content at later growth stages. IoT sensors monitored plant health and environmental conditions effectively.	Hasyer et al. (2023)
Lettuce	Hydroponic system	Plant morphological parameters captured through LED lighting	Plants grown under Blue LED light shows increase in biomass, leaf area and leaf pigment	Namgyel et al. (2018)
Mushroom	Monitoring the nursing room environment	Temperature, humidity, light and CO_2	Web-based application automates and maintains the room temperature for mushroom cultivation	Shakir et al. (2019)
Mushroom	Architecture for IoT and machine learning in mushroom classification	Temperature and humidity	Ensemble model outperforms in classifying toxic mushrooms	Rahman et al. (2022)
Paprika	Non-circulating drip system	Water and nutrient	Uniformity of nutritious water distribution and minimizes decay	Sudana et al. (2019)
Spinach	Controlling of spectral range by selecting appropriate LED light	Temperature, humidity and soil moisture	Recorded interactions between different color spectra and plant growth	Marcos et al. (2020)
Tomato	Industrial greenhouse environmental lighting conditions	Temperature, humidity, solar radiation, NDVI values	Monitored plant growth and photosynthetic activity	Bicans et al. (2019)
Flowers				
Gerbera	Controlling brightness of LED lamps in green house with soil moisture control	Ambient brightness between 3000-5000 lux, with 70-80% of soil moisture	Automatically adjusts the brightness and soil moisture to a proper range for gerbera growing.	Kumkhet et al. (2022)
Orchid	Monitoring orchids for optimum water requirement	Soil temperature is maintained between 15° C and 28°C	Automatically irrigates and maintains the optimum soil moisture in the range of 60-85% for orchids grown in potted medium	Al Rafi et al., 2018
Fruits				
Jackfruit	Fruit growth measurement and monitoring system using 2-axis joystick sensor attached to the crop.	Increase in circumference of fruit, mean radial growth change	Low power internet of growth measuring things – Agristick measure and monitors the growth of jackfruit	Sengupta, et al. (2022)
Mango	Improving the shelf life of fruit in cold chain storage	Temperature, CO_2 and volatile organic compounds (VOC) collected	Monitor the quality parameters of Indian mangoes with sensors and estimated optimum temperature and CO_2 levels to freshly preserve the fruits	Bardhan et al. (2022)

services), makes it difficult for farmers, especially in developing regions, to adopt these technologies.

Developing more affordable IoT solutions through local manufacturing, cost-effective designs, and economic models tailored to the financial capabilities of farmers can help reduce the barrier to entry. Exploring alternative energy sources like solar or wind can also reduce operational costs.

System adaptability

IoT devices and systems often struggle to adapt to the diverse environmental conditions in agriculture. The varying landforms, climates, and unpredictable weather conditions can affect the accuracy and reliability of data collection and system operations.

Designing IoT systems that are robust, adaptable, and capable of handling diverse agricultural environments is crucial. Incorporating advanced techniques for environmental correction and ensuring systems are resilient to harsh conditions will improve reliability.

Data management and reliability issues

Ensuring the reliability and integrity of data collected by IoT devices is a significant challenge. System failures, battery issues, and environmental factors can lead to inaccurate data, which undermines decision-making processes. Additionally, the massive amount of data generated requires advanced storage and processing solutions.

Implementing fault-tolerant systems, reliable data storage solutions, and scalable management platforms is essential. Enhancing the reliability of data transmission and incorporating robust fault-tolerance mechanisms will ensure the integrity and usability of data.

Interoperability and standardization issues

The lack of standardization and interoperability among different IoT devices and systems poses a challenge in agriculture. This inconsistency can lead to communication issues, system inefficiencies, and increased costs due to incompatibility between various technologies.

Establishing standardized communication protocols and ensuring interoperability between different IoT devices and systems will streamline operations and reduce costs. Embracing new technologies can further enhance communication capabilities and support the widespread adoption of IoT in agriculture.

SUMMARY AND FUTURE ROADMAP

This review focuses on promoting smart farming mechanisms by establishing IoT in horticulture by optimizing resource inputs, reducing labor costs and better crop management. This would help farmers automate crop cultivation in a viable manner based on the soil and environmental parameters. With the advancement of hardware and software technology, it is possible to implement many crop monitoring systems. The future scope of IoT research in horticultural crops is vast and holds great potential for advancements in the industry. The integration of IoT components with artificial intelligence and machine learning to provide actionable insights and optimize crop cultivation and management is a major future study. Standardization of IoT components to ensure interoperability and seamless integration of various devices and systems is crucial. It is important to develop low-cost and easy-to-use IoT components that are accessible to small-scale farmers. Combining IoT technologies with artificial intelligence and robotics can result in autonomous farming systems. A better focus on enhancing sensor accuracy, developing advanced analytics algorithms, and integrating multiple sensor types for comprehensive monitoring has become necessary. Future research could explore advanced water management techniques, such as closed-loop systems that consider plant water requirements, evapotranspiration rates, and soil characteristics to provide precise irrigation schedules. With the ever-increasing demand for food, the horticultural industry is facing new challenges that require innovative and sustainable solutions.

CONCLUSION

The Internet of Things (IoT) in horticulture holds vast potential for significantly enhancing the efficiency, productivity, and sustainability of agricultural operations. While challenges such as the cost and complexity of implementing IoT systems remain, the benefits of IoT in horticulture are likely to increase, especially as labor shortages in the agricultural sector persist. The rising cost of labor may offset the capital expenditure involved in establishing IoT infrastructure, making the technology more widespread in the near future. IoT enables precise monitoring and control of irrigation, fertilization, and energy use, leading to significant water, nutrient, and energy savings which will counter balance the capital cost. These efficiencies not only reduce operational costs but also promote sustainable farming practices, further accelerating the adoption of IoT in horticulture.

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