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Intelligent Irrigation Systems: A Review of IoT-Enabled Smart Irrigation Technologies

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ABSTRACT:

The Internet of Things (IoT) has emerged as a pivotal technology for revolutionising agricultural practices, particularly in the domain of irrigation management. IoT-enabled smart irrigation systems leverage advanced sensors, wireless communication, and data analytics to optimise water usage, enhance crop productivity, and promote sustainability in agriculture. This review paper explores the core components, architectures, and applications of IoT-based irrigation technologies, with an emphasis on their impact on resource efficiency and agricultural sustainability. IoT-enabled smart irrigation systems integrate various sensors to monitor critical parameters such as soil moisture, temperature, humidity, and rainfall. The data collected by these sensors is transmitted to cloud-based platforms or centralized control systems for real-time analysis and decision-making. This enables precise irrigation scheduling, ensuring that water is delivered to crops only when and where it is needed. The paper also discusses the role of wireless sensor networks (WSNs), automated irrigation controllers, and advanced communication protocols in facilitating remote management and reducing human intervention. Furthermore, the review addresses the benefits of IoT-based irrigation systems, including significant water conservation, cost reduction, and improved crop yield. However, challenges remain, including high initial setup costs, the need for reliable connectivity in remote agricultural regions, energy consumption, and data security concerns. The paper also highlights emerging trends, such as the integration of artificial intelligence (AI) for predictive analytics and machine learning to enhance irrigation decision-making processes further. his review provides insights into current advancements, challenges, and future directions for IoT in irrigation technology, offering valuable perspectives for researchers, practitioners, and policymakers.

Keywords: Internet of Things (IoT), Smart Irrigation Systems, Automated Irrigation, Water Conservation, Soil Moisture Sensors, Wireless Sensor Networks (WSNs).

Introduction:

The advent of the Internet of Things (IoT) has brought significant transformation to various sectors, and agriculture is one of the most prominent fields benefiting from this technological revolution. In the realm of agriculture, the application of IoT in smart irrigation technologies has paved the way for more efficient, sustainable, and precision-based farming practices. The integration of IoT in irrigation systems not only optimizes water usage but also enhances crop productivity, minimizes environmental impact, and helps farmers make data-driven decisions. Smart irrigation refers to an advanced irrigation system that uses automated devices and sensors to monitor and control water usage in agricultural fields. By leveraging real-time data, these systems can adjust irrigation schedules, detect soil moisture levels, monitor weather patterns, and even forecast crop water needs. This combination of sensors, connectivity, and analytics leads to precision irrigation, where water is delivered precisely when and where it is needed, reducing water wastage and increasing efficiency. The world is facing increasing challenges related to water scarcity, climate change, and the need for sustainable agricultural practices. Agriculture accounts for a significant portion of global water consumption, and inefficient irrigation practices have often led to water wastage, soil degradation, and reduced crop yields. IoT-enabled smart irrigation systems offer a solution to these problems by allowing farmers to monitor and manage water resources more effectively.

Sensors are placed in the soil to measure various parameters like soil moisture, temperature, and pH levels. Other sensors may monitor environmental factors such as humidity, rainfall, and temperature. Actuators control irrigation equipment such as sprinklers, drip lines, and valves. Based on the data received from sensors, actuators adjust water flow to ensure optimal irrigation. By optimizing irrigation schedules and providing crops with the ideal amount of water, IoT-based systems help to improve soil health and promote optimal plant growth. This results in healthier crops and, in many cases, higher yields. The data collected by IoT systems can also help farmers detect early signs of plant stress or disease, allowing for timely intervention and further improving yields. One of the most significant benefits of smart irrigation is its ability to conserve water. Traditional irrigation systems often lead to overwatering, as they follow pre-set schedules regardless of soil moisture or weather conditions. In contrast, IoT-based systems adjust irrigation in real time based on data from soil moisture sensors, weather forecasts, and environmental conditions. This targeted watering ensures that crops receive the exact amount of water they need, reducing water wastage.

IoT-enabled smart irrigation provides farmers with valuable data about their crops, soil, and environment. With access to real-time information, farmers can make data-driven decisions about irrigation, fertilization, pest control, and other aspects of crop management. This reduces the need for guesswork and improves overall farm management practices. In addition to water conservation, IoT-enabled irrigation systems contribute to environmental sustainability by reducing the need for chemical fertilizers and pesticides. By optimizing irrigation, the systems help prevent waterlogging and soil erosion, both of which can negatively affect the environment. Though the initial investment in smart irrigation systems may be high, the long-term cost savings can be significant. Reduced water consumption, lower energy usage, and increased crop yields can offset the initial cost of installation. Furthermore, the ability to monitor and control irrigation remotely reduces labour costs for farmers.

Literature Review:

S. No.	Title, Year, Author	Over view	Results
1	Sensor based smart agriculture with IOT technologies Dr. Pyingkodi K. Nanthini Jan, 25, 2022	IoT in agriculture offers significant benefits, including increased crop yields through precision farming, water conservation via smart irrigation, reduced chemical usage, improved farm efficiency, and enhanced decision-making driven by real-time data. However, its adoption faces challenges such as interoperability and standardization, data security and privacy concerns, energy efficiency in remote operations, scalability and reliability of systems, and ensuring cost-effectiveness for farmers. Future advancements include the integration of drones and satellite imaging for large-scale monitoring, computer vision and image processing for crop analysis, autonomous farming systems for automation, blockchain technology for supply chain transparency, and expanded applications in livestock and aquaculture monitoring. Key hardware components include sensors to monitor environmental factors, microcontrollers like Arduino and Raspberry Pi for processing, IoT modules for connectivity, actuators for system control, and energy harvesting systems such as solar and wind to ensure sustainable operations.	IOT sensor-based agriculture is now widely recognized as the new age of farming. It will shortly exchange traditional farming practices also enhance agricultural output. It is already in use in large farms and industrialized nations, but if properly implemented in countries such as India, China, and Africa, it may quickly solve world hunger. This contemporary farming approach has the potential to usher in a new era of green revolution and pave the way for progress in a nation like India, where farming is the major sector and market is based on it.
2	IOT in agriculture: The future of precision monitoring & data driven forming. Chen Liang, 2023	IoT in agriculture offers significant benefits, including increased crop yields through precise resource management, water conservation via smart irrigation, reduced chemical usage, improved farm efficiency through automation, and enhanced decision-making enabled by real-time data analysis. However, its adoption faces challenges such as ensuring interoperability and standardization among devices, addressing data security and privacy concerns, achieving energy efficiency and reliable power management, scaling systems for larger operations, and maintaining cost-effectiveness for widespread implementation. Future directions involve integrating AI and machine learning for	The rapid integration of IOT in agriculture marks a significant turning point for the industry, propelling it into the era of precision monitoring and data-driven farming practices. This transformative technological advancement brings forth a myriad of benefits and opportunities for farmers, enabling them to optimize their operations, improve productivity, and make well-informed decisions based on real-time data insights. By harnessing the power of IOT devices and systems, farmers can achieve unparalleled levels of accuracy in monitoring various parameters, ranging from soil moisture and temperature to crop health and livestock conditions.

		advanced predictive analytics, utilizing computer vision and image processing for crop monitoring, developing autonomous farming systems for greater automation, incorporating blockchain technology for transparent supply chains, and expanding IoT applications to livestock and aquaculture monitoring for a more holistic approach to smart agriculture.	
3	Overview of IOT data analysis in agriculture: benefits & challenges Chee Yen Leow, 2023	IoT in agriculture utilizes sensors, devices, and networks to monitor and optimize farming operations, collecting real-time data on environmental and crop conditions. This data is analyzed using advanced techniques like machine learning and predictive analytics, enabling precise resource management, weather forecasting, and crop health monitoring. The integration of IoT and data analysis provides numerous benefits, including increased crop yields and quality, reduced water and chemical usage, improved farm efficiency and productivity, enhanced decision-making and risk management, and ultimately greater profitability for farmers. However, challenges such as ensuring data quality and accuracy, addressing data security and privacy concerns, achieving interoperability and standardization among devices, managing energy efficiency, and maintaining cost-effectiveness and scalability need to be overcome for broader adoption and long-term sustainability in smart agriculture.	An overview of IOT and DA in agriculture has been pre sented in this paper. Several areas related to the deployment of IOT in agriculture have been discussed in detail. The sur vey of literature shows that there are lots of work ongoing in development of IOT technology that can be used to increase operational efficiency and productivity of plant and livestock. The benefits of IOT and DA, and open challenges have been identified and discussed in this paper. IOT is expected to offer several benefits to the agriculture sector. However, there are still a number of issues to be addressed to make it affordable for small and medium-scale farmers.
4	Swot-analysis Rinya & Ammutsonn iei, David Galea 2023	The first step in conducting a SWOT analysis is to define the objective by identifying the organization, project, or individual to be analyzed and clarifying the purpose and scope of the analysis. Next, information must be gathered from various sources, such as internal documents like reports and financial statements, and external sources like market research and customer feedback. Strengths are identified by examining internal capabilities and resources, including skills, expertise, and financial assets, while weaknesses are assessed by identifying internal limitations like skills gaps or financial constraints. Opportunities are explored by analyzing external factors, such as emerging market trends, evolving customer needs, and potential regulatory changes, to uncover avenues for growth and improvement.	In spite of its apparent simplicity, SWOT analysis can be misused by practitioners. The correct use of the tool is essential in ensuring that the right strategic action is defined in the process. It is good at drawing a picture of the current internal and external state of affairs, but it does not necessarily provide a guide to the strategic action, which is required. SWOT is more of a descriptive tool to conduct an overview of the environment.
5	IOT based smart crop-field monitoring & automation irrigation	IoT in agriculture offers transformative benefits, including increased crop yields through precise resource management, water	A PA agriculture irrigation system is developed with low complex circuitry. two sensors are used efficiently those are

	system B. Sridhar R. Nagaswararao	conservation via smart irrigation systems, reduced energy consumption, improved crop quality, and enhanced decision-making driven by real-time data analysis. However, its adoption is challenged by issues such as interoperability and standardization of devices, data security and privacy concerns, energy efficiency and power management in remote areas, scalability and reliability of systems, and achieving cost-effectiveness for broader accessibility. Looking ahead, future advancements involve integrating IoT devices for seamless connectivity, employing computer vision and image processing for detailed crop monitoring, developing autonomous farming systems for enhanced automation, incorporating blockchain technology for secure and transparent supply chains, and expanding IoT applications to other agricultural domains, creating opportunities for a more efficient and sustainable farming ecosystem.	temperature and moisture of soil in the circuit to get the calibrated information to the system. Two sensors and Raspberry pi microcontrollers of all three Nodes are successfully interfaced various Nodes. All observations and experimental tests proves that proposed is a complete solution to field activities, irrigation problems, Implementation of such a system in the field can definitely help to improve the field of the crops and overall production. . With the help of this approach the irrigation system completely automated also provides real-time information about the lands and crops that will help farmers make right decisions. The proposed cloud-based IOT approach for smart irrigation system demonstrates a robust, efficient, and scalable solution for precision irrigation management. The system integrates advanced sensors, IOT devices, and cloud computing to provide real-time monitoring, automated irrigation control, and data-driven decision-making.
6	Cloud based IOT approach for smart irrigation system: Design & implementation, Jhaer Isam Ishaq 2019	The integration of IoT in agriculture offers numerous benefits, such as increased crop yields, water conservation, reduced energy consumption, improved crop quality, and enhanced decision-making through real-time data analysis. However, challenges like interoperability and standardization, data security and privacy concerns, energy efficiency, scalability and reliability issues, and the high cost of implementation need to be addressed for broader adoption. Future advancements in this domain include integrating IoT with other smart devices, leveraging computer vision and image processing for precise monitoring, developing autonomous farming systems, incorporating blockchain technology for transparency, and expanding IoT applications to diverse agricultural areas, ensuring a more sustainable and efficient agricultural ecosystem.	The proposed cloud-based IOT approach for smart irrigation system demonstrates a robust, efficient, and scalable solution for precision irrigation management. The system integrates advanced sensors, IOT devices, and cloud computing to provide real-time monitoring, automated irrigation control, and data-driven decision-making.
7	Importance performance analysis-based swot analysis Richord M. Crowdera Gray B. Wills 2020	Conducting a SWOT analysis involves identifying key factors related to an organization or project and categorizing them into Strengths, Weaknesses, Opportunities, and Threats. This process facilitates a thorough evaluation of each quadrant to pinpoint areas for improvement, leverage strengths and opportunities, and develop strategies to mitigate threats. The benefits of this approach include a comprehensive assessment of organizational or project performance, identification of improvement areas, prioritization of	This study proposes an IPA-based SWOT analysis that adopts the Importance Performance Analysis, a technique for measuring customers satisfaction from customer satisfaction surveys, to systematically generate SWOT factors. As mentioned in the literature review, this study bridges the gap of the current SWOT analysis approaches by providing both quantitative and customer-oriented SWOT factors which improves a deciency of traditional SWOT analysis. which a customer satisfaction survey is analyzed to calculate the attributes importance and the

		resources, and enhanced decision-making. By aligning insights from the analysis with actionable plans, organizations can optimize their performance and resilience in dynamic environments.	attributes performance, and SWOT factors identification based on the IPA matrix.
8	Soil-plant relations along a soil-water gradient in great basin riparian meadows C. Jeanne, Robbin. J 2000	To study riparian meadows in the Great Basin, research begins by selecting sites with varying soil moisture levels and establishing transects perpendicular to stream channels to capture the soil-water gradient. Soil samples are collected at regular intervals along each transect for comprehensive analysis, including physical properties like texture, bulk density, and water-holding capacity; chemical properties such as pH, nutrient concentrations, and electrical conductivity; and biological properties like microbial communities and enzyme activities. Concurrently, plant surveys are conducted along the transects to identify species, record their abundance, and measure traits such as height, leaf area, and biomass. Community diversity and composition are calculated to provide insights into ecological patterns and processes, enabling a holistic understanding of the interactions between soil and vegetation in these dynamic environments.	The soil characteristics of the four vegetation types were similar to those found for other central Nevada meadow ecosystems (Weixelman et al. 1996, Cham bers et al. 1999), and differences among types could be explained by water-table depth. The vegetation types within shallower water-table depths, i.e., the wet and mesic meadows, tended to have higher organic matter, finer soil particle sizes, and higher soil moisture holding capacities than the types with deeper water tables. Redoximorphic features, in particular mottling, occurred where the depth to water-table fluctuated between soil wetting and drying, such as in the mesic and dry meadow type soils. Patterns in soil moisture content followed those of depth to water-table with the exception of the mesic meadow type in.
9	An effective method for crop monitoring using wireless sensor network N. Sakthipriya 2014	The application of IoT in agriculture offers significant advantages, including real-time crop monitoring, improved crop yields, reduced water and fertilizer usage, enhanced decision-making, and increased farm efficiency. Despite these benefits, challenges such as energy efficiency and power management, data security and privacy concerns, interoperability and standardization issues, scalability and reliability, and cost-effectiveness must be addressed to maximize its potential. Looking ahead, the integration of IoT with other smart devices, the use of computer vision and image processing, the development of autonomous farming systems, the incorporation of blockchain technology for transparency, and the expansion of IoT applications to diverse agricultural sectors will pave the way for smarter, more sustainable farming practices.	In this paper, we proposed real-deployment of WSN based crop monitoring which is designed and implemented to realize modern precision agriculture. End Users can tailor the mote operation to a variety of experimental setups, which will allow farmers to reliably collect data from locations previously inaccessible on a micro-measurement scale. Such a system can be easily installed and maintained. This paper successfully applies the wireless sensor networks on agro-ecology fields by investigating environmental situations. The complete real-time and historical environment information is expected to help the agro-ecological specialists achieve efficient management and utilization of agro-ecological resources.
10	IOT based agriculture (IOT): a detailed study or Architeature, security Santoshi Rudrakar	The adoption of IoT in agriculture brings a range of key benefits, including increased crop yields, water conservation, reduced energy consumption, improved crop quality, and enhanced security and data protection. Additionally, it fosters better interoperability and standardization, enabling seamless integration across systems. Key challenges,	According to SDG 2030 goal 2, the world is looking to promote sustainable agriculture to achieve zero hunger. Ag-IOT can become a major contribution in this direction and can be used in a variety of agricultural fields, such as farm monitoring, irrigation, pest monitoring, livestock monitoring, smart greenhouses, and smart poultry farms. This study reviewed 132

	2023	such as data security and privacy, energy efficiency and power management, scalability, reliability, and cost-effectiveness, must be overcome to fully realize its potential. Future directions in agricultural IoT involve integrating with other smart devices, leveraging computer vision and image processing for more precise monitoring, developing autonomous farming systems, incorporating blockchain technology for transparency and traceability, and expanding IoT applications to broader agricultural areas, all contributing to more sustainable and efficient farming practices.	articles related to Ag-IOT and IOT in general, covering topics such as Ag-IOT architectures, applications, security, and forensic issues. The findings of the study indicate that while much work has been done to create high-level Ag-IOT platforms, manufacturers and developers have not paid enough attention to security.

IOT SENSORS FOR IRRIGATION

1. **RS485 Soil Moisture & Temperature Sensor:** When dealing with an RS485 Soil Moisture and Temperature Sensor, the measurement parameters generally include several technical and functional aspects. These parameters can be categorized as **physical parameters** (soil moisture and temperature), **electrical parameters** (signal and power), and **communication parameters** (RS485 settings).

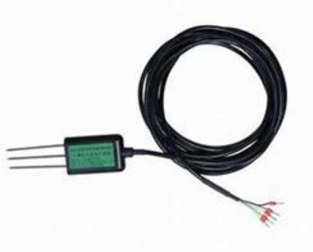

Figure 1 soil moisture

Draw backs: It can be complex to integrate, have higher power consumption, and may suffer from corrosion or communication issues. They're also more expensive and less effective in certain soil types or depths.

2.MP406 Soil Moisture Sensor: The MP406 soil moisture sensors are used in agriculture to provide accurate, real-time measurements of soil moisture levels, enabling optimized irrigation practices and improved crop management.

Figure 2 MP406 soil moisture

Drawbacks: It has drawbacks such as corrosion in saline soils, limited accuracy, short lifespan, calibration needs analog output interference, and no temperature compensation, making it less suitable for advanced applications.

3. SPH01-NB -- NB-IoT Soil pH Sensor: It is designed to measure the soil pH and soil temperature.

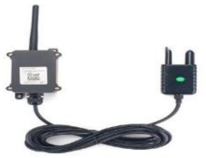

Figure 3 soil ph sensor

Drawbacks: It can depends on NB-IoT network availability, limiting its use in areas without coverage. It also only measures pH, requiring additional sensors for comprehensive soil health monitoring.

4. Temperature sensor (JXBS-3001): To monitor soil and air temperatures.

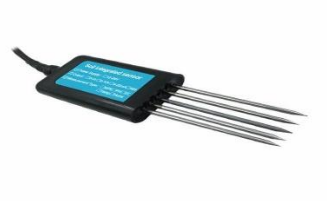

Figure 4 temperature sensor

Drawbacks: It has limited functionality (measuring only temperature), potential accuracy limitations, higher power consumption, and may not be suitable for extreme temperatures or high-precision applications without additional sensors.

5. Temperature and Humidity sensor(DHT11): To monitor temperature and humidity.

Figure 5 temperature and humidity sensor

Drawbacks: It have limited temperature and humidity range, lower accuracy, slow response time, and sensitivity to environmental factors make it unsuitable for precise agricultural applications, especially in extreme conditions or for critical monitoring.

6. SDI-12 Leaf Wetness Sensor TBSLWS1: To detect moisture on leaf surfaces.

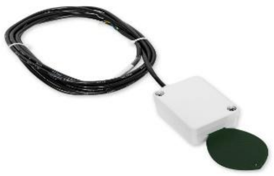

Figure 6 wetness sensor

Drawback: It requires SDI-12 infrastructure, adding complexity and cost. It only measures leaf wetness, necessitating additional sensors for comprehensive monitoring, and may require regular maintenance in harsh conditions.

7. LABART Soil Npk sensor LNPK-101: It measures nitrogen (N), phosphorus (P), and potassium (K) levels in the soil, providing valuable data for soil fertility assessment and crop management.

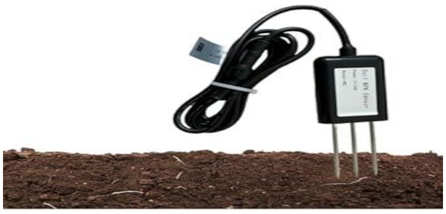

Figure 7 soil npk sensor

Drawbacks: It requires frequent calibration, may be sensitive to soil type, and measures only NPK nutrients. It’s also more expensive than basic sensors and has higher power consumption.

8. Soil 7 in 1 Sensor Modbus RS485 5V JXCT: used for soil npk, ph, ec, moisture, temperature and humidity measurement with high accuracy, fast response speed and stable output.

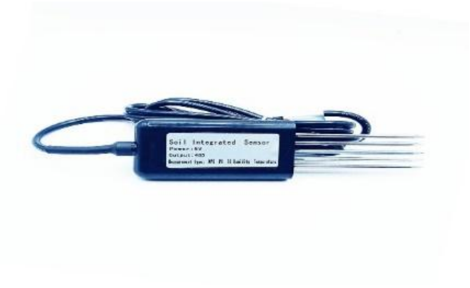

Figure 8 sensor modbus

Drawbacks: It requires complex setup and configuration, is expensive compared to simpler sensors, and may need frequent calibration. It also has limited range for certain environmental conditions.

9. SO-411 Oxygen Sensor: Measures oxygen levels in the soil, important for assessing root health and soil microbial activity.

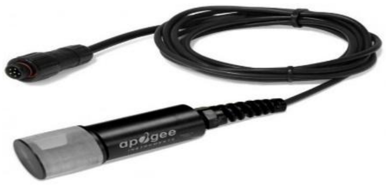

Figure 9 oxygen sensor

Drawbacks: It may have limited accuracy in certain conditions, require frequent calibration, and be sensitive to environmental factors. It may also have higher power consumption and limited range for specific applications.

10. Wind Speed Sensor: crop protection, optimize irrigation, ensure safe pesticide application, improve weather forecasting, and control soil erosion, leading to better decision-making and enhanced productivity.

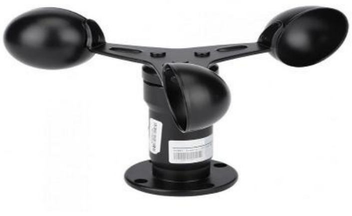

Figure 10 wind speed sensor

Drawbacks: It may require frequent maintenance due to wear from dust or debris, can be affected by sensor placement near obstructions, and may be prone to inaccuracies in extreme weather.

11. Waterproof light Sensor: optimize light conditions for crops, improve irrigation efficiency, and enhance overall farm management through real-time monitoring and data analysis.

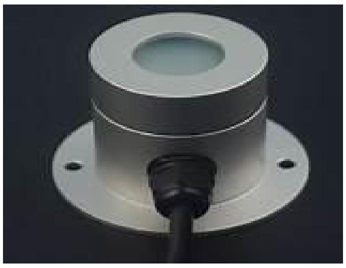

Figure 11 water proof light sensor

Drawbacks: It may be affected by dirt, dust, or plant growth obstructing the sensor, potentially causing inaccurate readings. They also require maintenance to prevent moisture buildup and corrosion.

12. 5-in-1 Weather Sensor: Time and Date, Temperature, Rain Rate, Dew Point, Forecast, Wind Speed, Humidity, Heat Index, Pressure, Wind Direction.

Figure 12 weather sensor

Drawbacks: It may have lower accuracy compared to individual sensors, requires periodic calibration, can be affected by environmental factors, and may have higher power consumption or higher initial cost.

Overall Observations:

Key Features	Sensor Types Used	Data Transmission Protocols	Advantages	Challenges	Applications	Environmental Impact
Soil Moisture Sensor-Based Systems	Soil moisture sensorse.g. [2], [3], [4] GS3, capacitive sensors) [2] , [3] sometimes integrated with temperature and humidity sensors[3]	Various, including MQTT, Wi-Fi [2], [3], [4] and LoRa. Some systems utilize proprietary protocols or direct connections.	Precise water delivery based on real-time soil moisture, levels, reduced water waste[2], improved water use efficiency, optimized crop yield.	Sensor accuracy and reliability, sensor maintenance [2] , cost of sensors and infrastructure, limited scalability in large fields, susceptibility to environmental factors (e.g., soil salinity).	Greenhouse [4] applications, field crops [3] , and various [2] plant types.	Reduced water consumption compared to traditional methods, potential for reduced energy consumption depending[2] on energy source.
Weather-Based Irrigation Systems	Weather stations [3] providing data on temperature, humidity, rainfall, solar radiation. May also incorporate evapotranspiration models.	Various, depending on weather station and system integration. May involve cloud-based platforms or direct connections.	Predictive irrigation scheduling based on weather forecasts, potential for significant water savings, improved water use efficiency.	Inaccurate weather forecasts, variations in microclimate difficult field conditions, potential for over- or under-irrigation due to model limitations.	Large-scale field irrigation, various crops.	Reduced water consumption compared to traditional methods, potential for reduced energy consumption with solar power.
Remote-Controlled Sprinkler Systems	Rain sensors, sometimes integrated with flow meters.	Wi-Fi, GSM, or other wireless communication protocols	Remote control and monitoring, flexibility in irrigation scheduling, potential for water savings with rain sensors.	System complexity, cost of infrastructure, potential for communication failures, dependence on reliable power supply, potential for malfunction of remote control mechanisms. Lawns, gardens, small farms, various landscaping applications.	Lawns, gardens, small farms, various landscaping application	Water savings with rain sensors, potential for increased [3] energy consumption [2] depending on system design.
AI and Machine Learning-Enabled Systems	Multiple sensor types (soil moisture, temperature, humidity, etc.), potentially including image data from drones.	Various, often involving cloud-based[3] platforms for data processing and model training.	Optimized irrigation scheduling based on complex data analysis, improved water use efficiency potential for increased crop yields adaptive control strategies.	Data acquisition and processing requirements model accuracy and reliability computational complexity high initial cost, potential for bias in model training data.	Precise irrigation for various crops large-scale applications.	Reduced water consumption potential for reduced energy consumption with optimized scheduling.

IoT-Based Drip Irrigation Systems	Soil moisture sensors sometimes including temperature and humidity sensors.	MQTT Wi-Fi or other wireless communication protocols	Precise water delivery, reduced water waste improved water use efficiency reduced Labor costs.	System cost sensor maintenance potential for clogging of drip lines susceptibility to environmental factors (e.g., extreme temperatures).	Various crops orchards, vineyards	Reduced water consumption potential for reduced energy consumption with solar power.
Multi-Sensor Integration Systems	A combination of soil moisture sensors, temperature sensors, humidity sensors, water level sensors, rain sensors [3] , etc.. Potentially including advanced sensors such as salinity sensors, pH sensors.	Various wireless protocols, often involving cloud-based platforms for data aggregation and analysis.	Comprehensive monitoring of environmental and soil conditions improved decision-making for irrigation scheduling optimized water and nutrient management.	Increased system complexity higher initial cost, data management challenges potential for sensor failures	Large-scale field irrigation greenhouses various crops.	Reduced water and energy consumption improved resource management.
Mobile App-Based Systems	Various sensor types, depending on system design.	Wi-Fi, GSM, or other wireless communication protocols.	Remote monitoring and control, user-friendly interface, improved accessibility for farmers.	Dependence on mobile network coverage, potential for app malfunctions, security concerns.	Various applications, depending on system design.	Reduced water consumption with optimized scheduling, potential for reduced energy consumption with solar power.
Cloud-Connected Irrigation Platforms	Various sensor [3] types, depending on platform capabilities.	Cloud-based communication protocols [3] (e.g., MQTT, HTTP).	Data storage and analysis [3] capabilities, remote monitoring and control [3] , integration with other farm management tools.	Dependence on internet connectivity, data security concerns, platform costs, potential for system failures due to cloud outages.	Large-scale irrigation management, various crops [3] , precision agriculture.	Reduced water consumption[3], potential for reduced energy consumption with optimized scheduling and solar power.

Limitations:

- Smart irrigation systems and IoT devices can be expensive to install, especially for large-scale agricultural applications.
- IoT devices require regular maintenance and updates to ensure proper functionality, which may require technical expertise not readily available in rural areas.
- Dependence on reliable internet or network connectivity can be a challenge in remote areas, affecting the performance of IoT systems.
- Sensors can sometimes provide inaccurate readings due to calibration issues, environmental factors, or sensor malfunctions, leading to improper irrigation decisions.
- IoT devices rely on continuous power, which can be problematic in areas without a stable electricity supply. Solar power options may also be limited during cloudy periods.
- IoT systems can be vulnerable to cyber-attacks, leading to data theft, unauthorized access, or control over irrigation systems.
- Scaling up IoT-based systems for larger farms or varied crops may require significant adjustments, increasing complexity and costs.
- Some IoT devices may have environmental impacts due to battery disposal or the materials used in manufacturing sensors and electronics.
- Farmers may be resistant to adopting IoT technology due to a lack of technical knowledge, training, or trust in new systems.

Conclusion:

IoT-based smart irrigation systems are transforming modern agriculture by enhancing the relationship between soil, water, and plants. These systems use a network of sensors to collect real-time data on soil moisture, weather conditions, and plant water needs, allowing for precise and automated irrigation. This targeted approach prevents over-watering and under-watering, ensuring that crops receive the optimal amount of water at the right time. As a result, water efficiency improves significantly, with potential reductions in water usage by up to 30-50%, which is critical in regions with limited water resources. Additionally, these systems contribute to better crop health and higher yields by optimizing nutrient absorption and promoting stronger root development. The automation of irrigation also reduces labour and energy costs, making it a cost-effective choice for farmers. Furthermore, minimizing water runoff lowers the environmental impact, preventing the leaching of fertilizers and pesticides into nearby water bodies. This data-driven method supports sustainable agriculture by enabling farmers to make informed decisions based on accurate data, leading to more productive and environmentally friendly farming practices. As IoT technology advances, future smart irrigation systems will likely incorporate more sophisticated analytics, AI-driven predictions, and integration with weather forecasts, further improving agricultural efficiency and resilience to climate change. Overall, IoT-driven smart irrigation supports sustainable farming by allowing data-based decision-making, leading to more productive and environmentally friendly agricultural practices. As the technology continues to evolve, future systems are expected to integrate advanced analytics, AI predictions, and weather forecasting, further enhancing agricultural efficiency and resilience to climate variability.

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