

A Review of Smart Irrigation Technologies

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Abstract

Countries around the world are increasingly collaborating to enhance agricultural efficiency by integrating emerging technologies into farming practices. One critical area of focus is improving irrigation efficiency, which is essential for the sustainability of agricultural production. Smart irrigation techniques, supported by wireless communication systems, advanced monitoring devices, and sophisticated control strategies, offer promising solutions for optimizing irrigation scheduling. This Paper explores a broad spectrum of scientific approaches to smart irrigation by reviewing a wide range of relevant literature. It encompasses diverse topics, including irrigation methods, decision-making processes, and the technological tools employed. The research is primarily based on scientific publications from the past four years, authored by researchers from across the globe. Special attention was given to various notable irrigation initiatives to provide a comprehensive perspective.

Keywords: Real-time irrigation scheduling, the role of the Internet of Things (IoT), the necessity of reliable internet connectivity, smart sensing technologies, and energy harvesting mechanisms.

1. Introduction

Agriculture is a fundamental industry and the backbone of many economies. The automation of agriculture is a growing concern and a critical focus for countries worldwide. As the global population continues to rise, the demand for food has surged. The increasing need for food, coupled with changing consumer preferences, has made it increasingly challenging for the agriculture industry to develop methods and practices that meet these rising demands and evolving requirements [1], [2], [3]. Agriculture plays a pivotal role in society, driving improvements in food production and technological advancements. It is crucial to ensure that upgrades are continuously made within this sector to improve its overall efficiency and outcomes. Technological innovations in food production are necessary to meet the advancing needs of consumers [4]. Given that many countries rely heavily on the agricultural sector, optimizing agricultural resources is of utmost importance [5]. Smart irrigation is emerging as a key

area of scientific development, using data-intensive methods to enhance agricultural productivity while minimizing environmental impact. Modern agricultural operations generate vast amounts of data from various sensors, which contributes to a deeper understanding of both the operating environment and the activities within the industry [6], [7], [8], [9]. This data enables more accurate decision-making and resource optimization, thus ensuring the sector meets its objectives efficiently. By implementing smart irrigation technologies, water conservation becomes a key factor in contributing to the United Nations' Sustainable Development Goals (SDGs), specifically Goal 6 and Target 6.4. Achieving the SDGs related to water and the environment is possible with the use of smart irrigation systems, which offer sustainable benefits and help create a better planet for all [10], [11], [12], [13]. SDG 6 focuses on ensuring clean water and sanitation for all, with various targets and indicators connected to water functions and services,

including irrigation. Target 6.4 addresses water scarcity, with indicators focusing on water use efficiency and water stress (WS) [14], [15], [16]. The effectiveness of these indicators largely depends on the quality of the available water data. Therefore, the increasing demand for healthier and more sustainable

food systems requires improvements in the development and management of irrigation systems. Figure 1 shows Architecture of Smart Irrigation System.

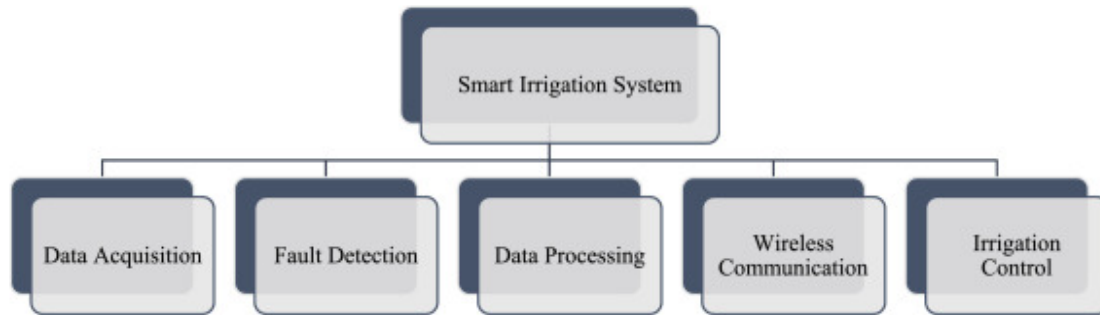


Figure 1 Architecture of Smart Irrigation System

2. Soil and Weather Monitoring

Efficient and effective monitoring systems significantly impact plant growth and are crucial in designing an effective irrigation control system that enhances food production while minimizing water loss. In the context of precision irrigation, monitoring involves collecting real-time data that reflects the status of the plant, soil, and weather conditions in irrigation areas. The Internet of Things (IoT) and Wireless Sensor Networks (WSN) play vital roles in this process. IoT has enabled the development of low-cost technologies that enhance control and monitoring systems for irrigation. WSNs also contribute significantly by providing real-time monitoring for precision farming. These systems involve networks of wireless sensor nodes that sense, compute, and transmit data on various environmental parameters. Soil moisture is a critical parameter for plant growth, and effective monitoring of soil moisture content is essential to ensure an optimal irrigation schedule. Soil moisture sensing is primarily based on low-cost capacitance-based sensors, which operate on the principle of dielectric devices. The goal of soil monitoring in smart irrigation systems is to accurately measure soil moisture content using advanced technologies. These sensors are typically buried in the root zones of trees, shrubs, or turf, where they measure moisture levels and transmit the

readings to the controller. This method provides vital information that helps design and implement irrigation activities for optimal results. Two main soil moisture sensor-based systems are commonly used: the suspended cycle irrigation system and the water-on-demand irrigation system. The suspended cycle system functions similarly to a traditional timer controller, with predefined schedules for watering, duration, start, and end times. The difference is that this system will automatically stop the next scheduled irrigation if the soil moisture is sufficient. In contrast, the water-on-demand irrigation system does not rely on pre-programmed schedules or fixed durations. Instead, the user sets a moisture threshold, and irrigation begins when the soil moisture falls below the required levels. In addition to soil moisture monitoring, weather monitoring plays a crucial role in irrigation management, particularly for large cropping areas. By assessing the weather and surrounding environmental conditions, the system can identify risks and develop strategies to mitigate potential adversities. WSNs again prove essential here, as they connect various sensors to monitor environmental factors. Real-time monitoring occurs through data analysis from these sensors, with a feedback loop that activates control devices when necessary. Another IoT-based weather monitoring

system has been implemented to assess factors such as humidity, air temperature, wind speed, solar radiation, and soil moisture levels. Weather-based sensors, which are interfaced with wireless communication standards, allow for the transfer of real-time data. This enables the collection of detailed environmental information, helping to develop irrigation strategies that improve long-term irrigation practices.

3. Water Management

Water management is a critical concept in irrigation, particularly in the face of global water scarcity. The increasing lack of clean water has become a significant concern worldwide, and it is crucial that agricultural sectors, along with other industries, prioritize this issue. Water management refers to the careful regulation of soil moisture to ensure that the optimum level and quantity of water are applied at the right time. Effective water management is vital for the agricultural sector, as it can reduce costs while boosting crop production. It also allows agricultural organizations to efficiently manage resources and carry out necessary activities accordingly. Given that numerous projects are being executed at various scales, it is essential to assess whether these projects will be effective in the long term. An increasing number of organizations are now focusing on conserving natural resources due to the growing concern over their scarcity. Among these resources, water is one of the most crucial and valuable assets that needs to be preserved and protected. With the substantial amount of water consumption involved in irrigation, organizations in the agricultural sector must be particularly mindful of developing strategies to optimize water usage. Therefore, effective water management solutions are necessary to provide numerous benefits to the agriculture industry. The external environment is highly unpredictable, and it can significantly impact agricultural activities. For example, fluctuations in fuel prices can increase the cost of pumping irrigation water. When fuel prices rise, the expenses for irrigation pumping also increase, potentially affecting the overall efficiency of agricultural projects. Through effective water management, organizations can develop additional reservoirs and implement strategies to minimize these

risks and negative impacts. A fundamental aspect of effective irrigation water management is understanding the relationship between soil, crops, and water. To carry out successful agricultural activities (such as irrigation), it is crucial to gather sufficient knowledge about the processes and products involved. Without this knowledge, it would be impossible to manage and control irrigation practices effectively, especially in adverse conditions, ultimately reducing overall performance. Water management is critical for several reasons, including ensuring optimum efficiency. By applying water management techniques, it is possible to ensure that crops receive the proper amount of water in dry areas or during periods of insufficient rainfall. In regions where water is limited, it is essential to focus on water management to ensure timely distribution and application. Furthermore, in many areas with low rainfall, adequate water storage is necessary to overcome the challenges of scarce precipitation.

4. IoT And Smart Systems Used in Irrigation

4.1 Communication Technologies in IoT for Irrigation

Effective communication technologies are critical for the successful implementation of IoT devices in irrigation systems. The choice of communication technology depends largely on the specific environment where it will be applied. IoT devices for irrigation can be broadly classified into two categories based on their communication capabilities. The first category includes devices that function as nodes, transmitting small amounts of data over short distances while consuming minimal energy. The second category consists of devices capable of transmitting large volumes of data over long distances, albeit with higher energy consumption. There are several wireless communication standards available for IoT devices, generally divided into those suited for short-range communication and those optimized for long-range communication. Among the most widely used and effective communication technologies is Wi-Fi. Its accessibility and support by many low-cost IoT devices make it a popular choice, though it has some limitations, such as area coverage and range. Another widely used wireless technology is the Global System for Mobile Communication

(GSM), which provides long-range communication and requires only a mobile plan from a service provider that operates in the area. More recently, technologies such as Long Range (LoRa) and Message Queuing Telemetry Transport (MQTT) have gained attention. LoRa offers very long-range communication, making it ideal for remote areas without network coverage. While MQTT, known for its low overhead and power consumption, is gaining popularity, it is still not widely used in irrigation systems.

4.2 Cloud Technologies in IoT for Irrigation

Cloud computing is another crucial technology in IoT-enabled irrigation systems, offering robust data storage and processing capabilities. Two primary storage systems commonly used are cloud storage and traditional databases, both of which allow organizations to save and access critical data as needed. These systems support the concept of big data, involving large datasets that organizations can leverage for various purposes. Middleware also plays a vital role in IoT, enabling the connection of programs that were not originally designed to work together, facilitating smoother integration of systems. In the context of agriculture, particularly irrigation systems, data gathered by IoT sensors is typically processed in the cloud. Users can access this data remotely by connecting to the cloud. The cloud serves as a storage hub for all monitored data, making it available when required. Cloud technology offers

both paid and free options for data storage, retrieval, and analysis across multiple devices and platforms. This accessibility enhances performance efficiency by enabling users to access and analyze data whenever necessary. Additionally, the cloud facilitates research and development by storing valuable data that can improve operational practices and outcomes. Cloud technology is also employed in irrigation systems to generate alerts via algorithms designed to mitigate risks and hazards. These alerts help users adjust their operations and take preventive measures, reducing the likelihood of negative events. Various cloud-based programs are available to assist in irrigation, each with its own set of features, cost structures, and applications. The use of cloud technologies in irrigation helps reduce risks, improve work efficiency, and achieve desired outcomes.

4.3 Benefits of IoT Systems in Irrigation

The integration of IoT systems into irrigation brings numerous benefits, making it an attractive solution for modern agricultural practices. Some of the key benefits include a reduction in overall water consumption, improved cost-efficiency, higher performance efficiency, reduced energy consumption, and less wastage of crops. Figure 2 illustrates the advantages of utilizing IoT systems in irrigation processes, showcasing how this technology optimizes water usage and enhances agricultural productivity.

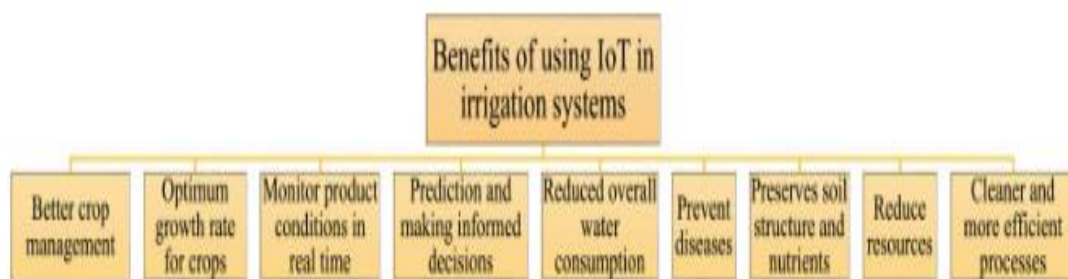


Figure 2 Benefits OG IOT Irrigation System

5. Discussion

5.1 Use of IoT and Big Data for Optimization of Irrigation Systems

IoT systems generate vast amounts of data by continuously monitoring various parameters in

real-time. In the context of irrigation, this data becomes a significant component of "big data." As the volume of data grows, it becomes crucial to develop mechanisms that efficiently assess,

manage, and utilize this information. Given the complexity of managing such large datasets and the potential strain it places on natural resources, there is a growing need for sustainable management practices for big data. Several strategies have been proposed to ensure the effective handling of big data in irrigation systems. These include utilizing blockchain technology for data security and transparency, eliminating unnecessary data to focus only on relevant information, powering IoT devices using solar energy for sustainability [1], and applying clustering techniques to reduce the overall volume of data. Additionally, implementing efficient algorithms and leveraging sustainable resources are key approaches to managing big data in irrigation systems. While big data holds immense potential to optimize irrigation, it is crucial to ensure that the information is well-managed and controlled to maximize its benefits. Furthermore, although IoT devices collect large volumes of valuable data, the analysis of this data is equally important for optimizing irrigation based on weather conditions and crop requirements. Many organizations involved in irrigation are capable of collecting the necessary data, but often struggle with properly analysing it to derive meaningful insights. This lack of effective data analysis presents a significant barrier to improving operational efficiency and reducing risks associated with irrigation activities. Figure 3 shows Barriers of smart irrigation systems.

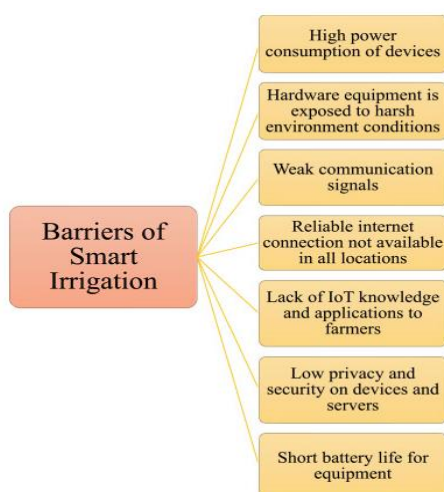


Figure 3 Barriers of Smart Irrigation Systems

5.2 Sustainability in Irrigation Systems

Sustainability is a critical aspect of irrigation systems, as it ensures the long-term viability and effectiveness of water management practices. To maintain sustainability within any system, it is essential to strike a balance between the three pillars of sustainability: economic, social, and environmental. Each of these pillars plays a crucial role in optimizing irrigation processes while minimizing negative impacts. Economic Sustainability: This aspect focuses on ensuring that irrigation practices are cost-effective, reduce waste, and improve the overall financial performance of agricultural operations. Figure 4 shows Potential Economic, Environmental and Social Benefits of The Irrigation System.

- **Social Sustainability:** This pillar emphasizes the need for irrigation systems to support the welfare of communities by ensuring equitable access to water, fostering local job creation, and enhancing the quality of life for farmers and stakeholders involved. Environmental
- **Sustainability:** The environmental aspect of sustainability in irrigation revolves around minimizing water waste, preserving ecosystems, and ensuring that the irrigation process does not deplete natural water resources or harm the surrounding environment.

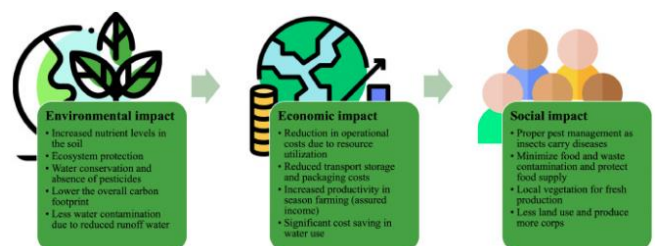


Figure 4 Potential Economic, Environmental And Social Benefits of The Irrigation System

5.3 Security and Data Acquisition

Advancements in technology have paved the way for innovative methods of collecting data from sensors deployed in agricultural fields. Among the most effective means of data acquisition is the use of drones. Drone technology enables the collection of valuable data, such as aerial imagery of fields, which

would otherwise be difficult to obtain using traditional methods. This capability enhances the ability to monitor crop health, soil conditions, and irrigation needs from a unique vantage point, offering real-time insights for decision-making. Another emerging technology in data collection is the use of robots, which are equipped with sensors and actuators to perform various tasks, such as spraying water, monitoring soil moisture, scaring away animals, or even weeding. These robots are highly effective for irrigation purposes, as they can travel to designated areas within the field and perform automated tasks. In addition, robots can assess soil moisture levels and are equipped with sensors that help avoid collisions, ensuring efficient and precise irrigation operations.

Conclusion

Technological innovations have become crucial for businesses in today's fast-paced environment, with organizations across all industries striving to enhance their operations and scale effectively. In this context, irrigation and its related technologies can be optimized to maximize operational efficiency while achieving the desired performance outcomes. The Internet of Things (IoT) has revolutionized agriculture by automating various aspects of farming, making the entire process more effective and efficient. Additionally, sensory systems have been adopted by farmers to gain deeper insights into crop health, reduce environmental impacts, and conserve resources. However, despite these advancements, not all organizations have been able to successfully implement these technologies or fully utilize their potential. On the other hand, water scarcity, encompassing issues such as water stress, shortages, and crises, has emerged as a critical global concern. As a result, water management has become a priority, with organizations increasingly seeking solutions to conserve this vital resource while improving work efficiency. In today's landscape, a SMART irrigation system has become essential for organizations aiming to meet performance goals. The combined benefits of IoT and sensor systems are significant. IoT not only reduces the overall cost of technology but also enables more effective management and monitoring of irrigation systems. Moreover, Wireless Sensor

Networks (WSN) play a key role in real-time monitoring, supporting precision farming and irrigation activities.

Future Scope

The future of smart irrigation technologies is promising, with several key developments expected to enhance agricultural efficiency and sustainability:

- Integration with IoT and AI: Smart irrigation will utilize IoT and AI for real-time monitoring and automated water management.
- Data-Driven Precision Agriculture: Big data analytics will optimize irrigation schedules and improve crop yields.
- Remote Monitoring and Control: Farmers will be able to monitor and control irrigation systems remotely via smart devices.
- Sustainability and Water Conservation: These technologies will significantly reduce water usage and support sustainable farming.
- Government and Policy Support: Increased government incentives and policies will encourage widespread adoption.
- Integration with Renewable Energy: Smart irrigation systems will incorporate solar and other renewable energy sources.

With continuous advancements and increasing adoption, smart irrigation technologies are set to become a cornerstone of modern, sustainable agriculture.

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