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Systematic Review on Cloud and IoT-based Drip Irrigation System Leveraging Advanced Analytics

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***Abstract*—Modern agriculture is faced with one of the most challenging problems of all time: maximizing crop yields and preserving precious water resources at the same time. As a response to this issue, this research paper explores the integration of Cloud and Internet of Things (IoT) technologies into drip irrigation systems. A unique approach utilizing sensors, remote monitoring, and advanced analytics will significantly increase the productivity of agriculture while also ensuring that water is used efficiently. The purpose of this research is to examine the crucial role IoT devices play in data collection and transmission, as well as the use of cloud platforms for storing, analyzing, and gaining actionable insights based on the collected data using advanced analytics techniques. The goal of this article is to provide a comprehensive overview of the benefits as well as possible challenges that cloud-based and IoT-based drip irrigation systems present, thus paving the way for sustainable, data-driven agriculture that will lead to improved crop yields in the future, based on a systematic review of relevant literature.**

***Index Terms*— Agriculture, IOT (Internet of thing) Drip Irrigation, Yield Optimization, Precision Agriculture, Predictive Models, Sustainability, Real-time Data Processing, Resource Conservation.**

I. Introduction

The evolution of agriculture once dominated by manual labor and rudimentary tools has been influenced significantly by the rapid advancements in technology [1]. It has become increasingly apparent that the integration of Cloud Internet of Things (IoT) with advanced analytics is one of the most promising solutions when it comes to maximizing agricultural yields and ensuring sustainable farming [1,2]. With the support of advanced analytics, this systematic review explores the transformative potential of cloud-based IoT drip irrigation systems, fortified by advanced analytics, to exacerbate farming yields through the integration of

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advanced analytics. The multifaceted challenges of agriculture, including climate change, water scarcity, and other factors, necessitate adoption of more efficient irrigation techniques [3,4]. It is well known that drip irrigation is one of the most effective methods of conserving water and enhancing plant health since it delivers water directly to the root zone of plants [1].
Cloud and Internet of Things facilitate the seamless integration of numerous devices across vast agricultural expanses, gathering real-time data regarding soil moisture, weather patterns, and plant health [2]. Advanced analytics turn this data into actionable insights. In this way, farmers eliminate guesswork and ensure optimal water use by knowing when, where, and how much to irrigate. With real-time data collection and predictive analytics, farmers can anticipate pest attacks, disease outbreaks, and other threats [2,3]. Moreover, machine learning models, part of advanced analytics, can identify patterns and trends in crop growth, providing suggestions for crop rotation, soil enrichment, and other vital farming practices [4].

A. Drip Irrigation: An Overview

A drip irrigation system, which is also referred to as trickle irrigation, applies water slowly and precisely directly to the roots of the plant [5]. It is accomplished by connecting a network of valves, pipes, tubing, and emitters to the plants, ensuring that the water drips slowly to the roots of the plants, minimizing wastage and increasing absorption of the water [4].

Advantages of Drip irrigation

Water Conservation: The benefits of drip irrigation include the fact that it minimizes evaporation and runoff, as well as the tendency to save water by distributing water straight to the roots [4-5].
Fertilizer Efficiency: This method allows for fertigation which combines fertilization and irrigation. Adding water-soluble fertilizers to the system optimizes nutrient absorption [4-5].
Reduced Weed Growth: The first benefit is that as only the desired plants are receiving water, weeds which thrive under wet conditions will be suppressed, thereby reducing the competition for nutrients for the plants [5-6].
Disease Prevention: The direct root watering system reduces the amount of moisture on the plant surfaces, reducing the potential for diseases caused by excess moisture, like fungal diseases [7].
Flexibility: The system is flexible and can be adapted to take care of a variety of terrains as well as cater to a wide range of plant types and their specific needs [7-8].

Components of Drip irrigation

In an efficient drip irrigation system, several key components work in harmony to deliver precise and controlled watering to plants. PVC pipes, commonly used as mainline and submainline, serve as the foundation of the entire system [9]. Drippers or emitters are crucial components for precisely meeting the specific water requirements of each plant. They disperse water gradually and controllably. Keeping water quality high requires filters to remove particles that might otherwise clog emitters, so they can function uninterruptedly. A valve controls water flow, allowing the irrigation process to be initiated or halted as needed, ultimately leading to optimal plant growth and efficiency[11].

Challenges and Limitations

Maintenance: Using filtered water and cleaning it on a regular basis is essential to keep the system clean. If the system is not properly maintained, it can become clogged [10-11].
Initial Cost: The initial cost of setting up a drip irrigation system may be higher than the cost of traditional methods, but the long-term benefits often far outweigh these initial expenses over time [10-11].
Sensors to measure soil moisture levels, IoT devices for remote management and predictive analytics to forecast water needs are making drip irrigation smarter. Modern agriculture relies heavily on drip irrigation because of its many benefits. Water scarcity has become a growing concern worldwide, so drip irrigation has become an imperative method of irrigation. Combining this method with technological advancements promises sustainable and prosperous agriculture [12].

B. IoT in Agriculture

Internet of Things (IoT) refers to the network of physical devices that are connected to each other over the internet with sensors, software, and other technologies. From simple household items like thermostats and refrigerators to complex industrial machinery, these things can be anything [12-13]. A foundational idea is to make everyday objects smart by connecting them digitally and enabling them to receive, send, and gather data [14].

Several elements come together to make IoT possible:

Sensors: A sensor detects changes in the environment, such as temperature, light, or pressure, and converts this information into usable data [13-14].

Connectivity: There are a number of ways in which devices can transmit data, such as using Wi-Fi or Bluetooth technology, cellular networks, or other types of wireless communication.

Software: The programs analyze the collected data and make decisions based on the information gathered, or initiate actions based on the insights they produce [14].

Actuators: The input data might be processed by the device such that a physical action can be performed based on it, like switching off a light or adjusting the room temperature. The actuators enable this physical action [14].

IoT's value lies in its intelligence and automation such as smart thermostats that learn a household's routine and adjust heating and cooling accordingly. IoT can be used to improve supply chain efficiency, healthcare patient care, agriculture crop irrigation, and much more on a broader scale [13]. As computing power advances, hardware costs decrease, and wireless networks become ubiquitous, IoT is on the rise. As technology continues to advance, the boundaries of what the Internet of Things can do are expanding, resulting in a world in which devices work seamlessly together, increasing efficiency, safety, and convenience across a variety of sectors [14-15].

Agriculture Application

Modern technology is transforming agriculture, an age-old practice fundamental to human survival. This revolution is being driven by the Internet of Things (IoT), which connects, analyzes, and acts on real-time data. By interlinking various devices and systems, farmers can now make better decisions, maximizing resources and yields. Here are some pivotal applications of IoT in agriculture [16]:

Soil Moisture Monitoring: At different depths within a farm, soil moisture sensors measure water content and transmit it to a centralized system. The farmers can then understand when their crops need water and how much, ensuring efficient irrigation, conserving water, and ensuring optimum crop growth [17].

Weather Forecasting and Monitoring: Predictive analytics is used to process data collected by on-farm weather stations. Farmers can use accurate weather forecasts to plan their activities, such as sowing, fertilizing, and harvesting. Additionally, they can take preventative measures against potential adverse weather conditions [16-17].

Plant Health Analysis: Farmers can monitor plant health and growth using drones and ground-based sensors. Advanced imaging techniques can detect diseases, pests, or nutritional deficiencies in plants. Early detection reduces damage risk and ensures healthy crop yields [18].

Precision Agriculture: A combination of IoT and GPS technology allows precise application of water, fertilizers, and pesticides. Equipment can be guided to specific locations to ensure resources are utilized where needed most. Not only does this conserve resources but also reduces environmental impact [19].

Monitoring: Storage facilities monitor conditions like temperature, humidity, and gas levels to ensure the produce is stored properly. In this way, produce remains fresh and maintains its quality until it reaches consumers, reducing post-harvest losses [20].

C. The Advent of Cloud and IoT-Based Drip Irrigation

Drip irrigation based on Internet of Things (IoT) is a significant advancement in agriculture technology. It brings several benefits to farmers and the agricultural industry:

Integrated Systems:

A drip irrigation system that is integrated and centralized can be created through the use of cloud platforms and IoT. [21]:

Data Collection: There are several ways to collect data in the field, such as soil moisture sensors, weather sensors, and crop health sensors.

Data Storage: This data is then transmitted to the cloud, where it is secured and accessible anywhere via firewalls.

Real-time Processing: This data is analyzed in real-time using algorithms and analytics, so that insights and recommendations can be derived from it. For instance, they can determine the best time to water crops according to the weather and the amount of water they require.

Real-time Monitoring

Farmers can monitor and control their drip irrigation systems in real-time with IoT-based cloud systems [22],

Remote Monitoring: Any farmer with an internet connection worldwide can monitor his irrigation system remotely and easily using a web portal or mobile application.
Optimized Water Usage: Farmer can optimize irrigation schedules and water delivery rates using real-time data on soil moisture, weather, and crop needs, resulting in less water waste and associated costs.
Alerts and Notifications: A farmer has the option to receive alerts and notifications when issues are detected, such as low soil moisture levels or equipment malfunctions, enabling timely intervention

D. Advanced Analytics in Agriculture

Predictive analytics and prescriptive analytics play a crucial role in modern agriculture by harnessing data to make more informed decisions.

Predictive Analytics
Forecasting Future Events: Patterns and trends are identified by analyzing historical data collected by sensors, weather stations, and other sources. Weather, disease outbreaks, pest infestations, and diseases can be predicted using this in agriculture.
Preemptive Measures: A farmer can mitigate potential risks by forecasting future events. Farmers can, for example, strengthen drainage systems or move equipment and livestock to safer areas if predictive analytics show heavy rainfall is likely.
Crop Management: Crop management can also benefit from predictive analytics. It can forecast the optimal planting and harvesting times based on historical weather and crop yield data, helping growers maximize crops [23].

Prescriptive Analytics
Actionable Recommendations: The goal of predictive analytics is to not only predict outcomes but also suggest specific actions that need to be taken based on those predictions.
Optimizing Farm Operations: Prescriptive analytics can be utilized to optimize various aspects of farm operations, including irrigation, fertilization, and weather forecasts.
Resource Allocation: The use of predictive analytics can also help allocate resources efficiently and cost-effectively.
Crop Rotation Planning: Prescriptive analytics can also be applied to crop rotation planning, which can help maintain soil fertility and reduce pest pressure by recommending crop rotation based on soil health, crop yields, and pest resistance [24].
In this section 1, we review empirical studies, compare outcomes between traditional drip irrigation and technology-enhanced drip irrigation, and assess the real-world impact of integrating cloud-based IoT and advanced analytics into farming practices to address these central questions. It is the objective of section 2 to discuss a number of research papers relating to smart irrigation systems. A comprehensive picture of the present and future potential of this technological convergence in agriculture will be presented in section 3, where we will examine the methodology employed. The final section of the paper will deal with the results and challenges of the project. To summarize, the fusion of Cloud IoT with drip irrigation, driven by advanced analytics, represents a revolutionary step forward in the smart agriculture field.

II. Literature Survey

L. Hamami et al.[1] A published review examines the use of wireless sensor networks for irrigation purposes. The paper highlights the increasing significance of Wireless Sensor Networks (WSNs) in irrigation systems due to their capacity to provide real-time monitoring and automation. This leads to the effective use of water resources and enhanced agricultural productivity. This research investigates the various sensors used in these networks, their deployment methodologies, and their respective merits and drawbacks. The research also examines several communication protocols, energy saving strategies, and data processing approaches that are beneficial for irrigation WSNs. In conclusion, the work underscores the need of persisting in research and innovation in this field to attain future progress.
S. Velmurugan et al. [2], This article explores the use of soil moisture sensors and weather prediction tools to enhance irrigation schedules via the implementation of the Internet of Things (IoT). To enhance the comprehensiveness of the research, the author highlights the significance of efficient water management in agriculture, along with the possible hazards associated with excessive irrigation or inefficient water use in conventional practices. The suggested method utilizes soil moisture sensors to guarantee that crops get optimal quantities of water in real-time. Simultaneously, weather forecasting technologies estimate future weather

conditions, enabling irrigation to be changed properly in alignment with these predictions. Ultimately, the research should analyze the consequences of these systems on sustainable agriculture, the obstacles linked to widespread adoption, and the potential integration of sophisticated technology in the future.

Ghosh, S.; Sayyed et al. [3], The authors of the paper embody a significant change in conventional irrigation practices by integrating data mining, cloud computing, and mobile technologies. Diverse sensors are used to gather up-to-the-minute data on soil moisture, temperature, and other essential environmental characteristics. Data mining methods are used to examine and manipulate this data. The cloud enables effective storage, processing, and retrieval of enormous volumes of data, allowing dynamic modifications in irrigation. Data mining utilizes historical and real-time data to identify trends, forecast water requirements, and enhance water use via the analysis of both historical and real-time data. The suggested system may be shown in this study via simulations or real-world applications, highlighting its benefits in water saving, yield enhancement, and user-friendliness. In conclusion, the research may address the difficulties, scalability concerns, and future prospects for enhancing and expanding such systems in the future.

Swetha, R.N et al. [4]. Authors represent efficient water use and higher yields for corporate farming, the study proposes a smart drip irrigation system. An IoT-based system collects and relays soil moisture, temperature, humidity, and other vital parameters to a centralized database continuously. With IoT, irrigation scheduling is data-driven and real-time. This ensures that crops are provided with water at optimal times and in appropriate quantities, based on their actual needs. In addition, the collected data can be analyzed to predict water requirements based on historical patterns. IoT integration offers a significant advantage in remote monitoring and control of drip irrigation systems. In corporate farms that span vast areas, this is particularly useful, allowing managers and agronomists to make informed decisions without physically visiting all sites. Embedding empirical evidence or case studies will likely be presented to prove the system's efficiency and benefits. Research and development in this domain may discuss implementation challenges, potential scalability issues, and future directions.

El Mezouari et al. [5] This paper presents a sophisticated IoT-based agricultural production monitoring system that utilizes a network of interconnected sensors to collect real-time data related to agricultural production. The user-friendly interface of this system relays a variety of data to farmers that ranges from soil moisture levels to climate conditions. A farmer with access to this real-time information has the capability of controlling various farming operations remotely, helping to not only optimize production but also reduce the amount of time they have to spend on manual labor, thereby simplifying their daily tasks.

Mabrouki J et al. [6] A smart irrigation system was developed based on the Arduino UNO single-board computer. The system is integrated with resistive sensors for soil moisture, temperature, and air humidity, which provide real-time readings of these parameters. This system continuously tracks soil moisture, temperature, and air humidity. Additionally, if the soil moisture readings indicate excessive aridity, the system automatically activates a motor to initiate irrigation, ensuring that the plants receive the water they require.

Gomathy, C.K et al. [7] There has been a significant advancement in the field of irrigation. In addition to the DHT11 sensor, which continuously tracks temperature and humidity levels, the system is powered by a node microcontroller unit (MCU). As a result of the detection of soil moisture values, the system intelligently decides when to activate the pump to ensure that crops receive optimal watering conditions.

The reviewed literature on WSNs/IoT-empowered irrigation systems indicates significant progress achieved in the field, a number of gaps exist. Firstly, there is a lack of comprehensive inquiry into the integration of research findings, including the ways in which the irrigation sensors are deployed, communication protocols between devices, and a more substantial number of energy-saving strategies. Additionally, empirical evidence should be given more priority to understand socio-economic influences on adopting the technologies and longer sustainability and scalability issues, especially in smallholdings as a critical focus of the future research. Overall, such additional efforts will develop more holistic, practical, and sustainable solutions that can improve irrigation practices and enhance food security in the light of global trends, primarily represented by water scarcity and climate change.

III. Smart Irrigation System Monitoring

As a result of an IoT-enabled drip irrigation system integrating a sensor fusion approach, the proposed innovative drip irrigation system is set to revolutionize precision agriculture in the future. It is depicted in Figure 1 that a number of sensors, such as moisture sensors and water level sensors, are seamlessly integrated into a single process plant. These sensors are intelligently connected to IoT devices that are connected via Wi-Fi, resulting in a real-time data transmission process. This data is then securely stored in the cloud server, creating a robust data repository connected to a central control unit. It is important to note that the soil moisture sensors are connected to a microcontroller and a node MCU, which continuously monitor the soil moisture conditions. The microcontroller sets and manages the threshold values for moisture conditions and controls the irrigation pump through a solenoid to automate its operation. The sensed values from these sensors are accessible on a computer interface, and once these values exceed the preset thresholds, the pump will automatically activate and shut off depending on how much water is required for the plant. In addition to providing real-time access to these real-time data updates on a dedicated web page, a mobile app has also been developed, so that users can access crop field conditions anywhere and anytime with ease. The system can also be equipped with a water level sensor that will ensure that the reservoir is managed optimally to ensure optimal results. This comprehensive irrigation design considers multiple environmental factors to optimize irrigation, enabling precise and efficient management of agricultural water resources.

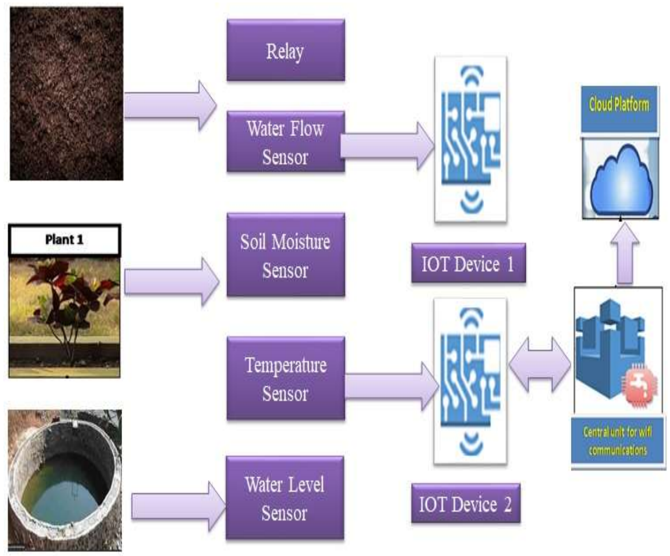

Figure 1: System Architecture

IV. Result and Discussion

A. Impact on Farming Yields

The integration of new technology such as IoT, cloud-based systems, and analytics has led to a substantial improvement in agricultural output during the previous two decades. Advanced technology have contributed to increased yields in many ways:

Efficient Water Usage: Precision Irrigation: Irrigation systems may be engineered to provide an exact quantity of water that is required by crops in real-time, using data acquired from sensors and weather predictions. By using this method, it may effectively mitigate the issues of excessive or insufficient irrigation in crops, therefore preventing both over irrigation and under irrigation. Plants require an adequate quantity of moisture to flourish, promoting rapid growth and increased productivity

Soil Health: The act of monitoring soil moisture levels, in addition to other pertinent data, has significant importance. By doing this, a more comprehensive comprehension of the soil properties may be obtained, enabling the implementation of fertilizers and irrigation in alignment with the soil features, eventually leading to increased crop productivity and resilience.

Reduced Costs

a. **Lower Operational Costs:** As a result of utilizing water and other resources in the most efficient way, farmers are able to reduce the costs associated with running their operations. Through precision irrigation, for example, farmers can reduce their water and energy costs associated with pumping and distributing water as well as their waste of fertilizers and pesticides.

b. **Labor Efficiency:** There has been substantial evidence that advanced analytics and automation can enhance the efficiency of labor allocation and reduce the need for manual labor to be required to monitor and control irrigation in a way that leads to cost savings over time.

Predictive Maintenance

Minimized Downtime: The use of cloud-based IoT systems can be used to predict when an irrigation system component will need to be replaced or when it will fail. By implementing this predictive maintenance approach, you ensure that your equipment is properly maintained and operational when needed. This minimizes downtime during critical times like planting and harvest. For crops to grow and yield consistently, uninterrupted irrigation is crucial.

Cost Savings: Implementing predictive analytics in preventative maintenance may effectively save expensive failures and emergency repairs. Implementing this strategy guarantees both the dependability of your system and a decrease in the expenses related to system maintenance.

B. Challenges and Limitations

The integration of sophisticated analytics and the Internet of Things in the cloud has many potential advantages for the agricultural industry, but it also comes with a number of obstacles and restrictions that need to be taken into account.

Initial Setup Costs: The cost of adopting Cloud IoT and advanced analytics systems in agriculture might vary depending on the magnitude of the deployment. Smaller farms with limited resources may find it excessively costly to acquire sensors, hardware, software, and establish the required infrastructure. It is crucial to recognize that these initial costs encompass the acquisition of sensors, hardware, and software.

Connectivity Issues: Lack of high-speed internet connection prevents many isolated and rural locations from accessing the internet at a fast pace. To guarantee optimal operation and real-time data transmission between the field and the cloud it is crucial for these systems to perform well in locations with restricted connection.

Data Privacy: Farmers may have several apprehensions about the security and ownership of their agricultural data when it is stored and processed on the cloud. Farmers often have several apprehensions about the confidentiality of their agricultural data and the individuals who possess authorization to access it. To address these issues, it is essential to develop strong data privacy protections and ensure clear comprehension of data ownership agreements.

Cybersecurity: A significant risk of cyber-attacks and data breaches can arise from the transmission and storage of data over networks and in the cloud. Farm data should be protected against intrusion and security breaches as well as implementing strong cybersecurity practices to mitigate these risks.

Technical Expertise: As remote areas may have fewer skilled personnel available and the availability of skilled personnel in rural areas can be a limitation, it may not be possible to implement and manage advanced technologies such as cloud IoT and analytics effectively. In rural areas, farmers and farm workers may need training to effectively utilize these technologies.

V. CONCLUSION

The systematic review of Cloud and IoT-based drip irrigation systems leveraging advanced analytics underscores the profound potential of this technology-driven approach in modern agriculture. With the integration of IoT devices and cloud platforms, we have been able to collect real-time data, monitor remotely, and utilize sophisticated data analytics, culminating in a comprehensive and data-driven irrigation strategy. This technology allows farmers to optimize resource allocation, crop health, and water management by harnessing the power of this technology. Even though there are many benefits to the use of this technology, there are still a lot of challenges to overcome, such as data security concerns, connectivity issues, and the need for user-friendly interfaces. This technology allows farmers to optimize resource allocation, crop health, and water management by harnessing the power of this technology. Even though there are many benefits to the use of this technology, there are still a lot of challenges to overcome, such as data security concerns, connectivity issues, and the need for user-friendly interfaces.

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