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3. Smart Irrigation Systems in Agriculture

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Abstract:

Smart agriculture involves incorporating cutting-edge technologies into agricultural management to enable remote monitoring, enhance resource utilisation, and automate pertinent procedures. This study examines the concept of intelligent irrigation systems, which entail augmenting automated irrigation systems with advanced cognitive capabilities. This is accomplished by utilising sophisticated control methods and integrating extensive data for analysis, with the objective of enhancing irrigation models and control. This approach incorporates techniques such as deep learning and machine learning. The objective of intelligent irrigation systems is to optimise agricultural output while limiting the environmental impact of crop cultivation.

These systems accomplish this by accurately dispensing water to crops at the ideal moment, in the suitable amounts, and in the proper position. This article gives the findings of a comprehensive examination of existing literature, which aimed to investigate the level of interest in technology utilised for irrigation purposes.

This examination specifically focuses on the techniques employed in soil crop cultivation, with a particular emphasis on irrigation rather than the possibility of fertigation. The soil serves as a medium for nutrient buffering, and it is common custom to apply solid fertilisers in the soil. By carefully cultivating the soil beforehand and consistently providing it with organic fertilisers, it is feasible to get exceptionally productive crop yields.

It is especially interesting to examine how the application of different levels and types of intelligent irrigation technology might improve crop development in the soil while encouraging optimal water utilisation. The technologies associated with artificial intelligence (AI), a discipline within computer science that explores and proposes methods for developing computers solutions that mimic human and animal behaviour or biology, present promising opportunities for automating irrigation.

Keywords:

Smart irrigation, IoT, Machine learning and Variable rate application

3.1 Introduction:

The Food and Agriculture Organization of the United Nations (FAO) predicts that the global population will reach approximately 9.1 billion individuals by the year 2050. This will lead to a significant surge in the already substantial worldwide demand for food. Considering solely developing countries, there is a potential for a 100% increase in world food production in the next years. The expected rise is projected to be seventy percent. Currently, seventy percent of the freshwater obtained from aquifers, streams, and lakes is used for crop irrigation in order to sustain the expected growth in food production. In order to match the demand, it is necessary for this percentage to increase. The diminishment of land, the accessibility of water, and biodiversity, in conjunction with climate change, are presently constraining the increase of agricultural output.

This has raised concerns regarding the future insufficiency of agricultural output to meet global food demand. The aforementioned variables, as well as several others, highlight the imperative to improve specific aspects of agricultural production and enable the utilization of non-traditional agricultural spaces, such as urban regions. As this situation unfolds, the increased accessibility of advanced technical choices becomes a catalyst for the shift towards more sophisticated agricultural systems. Implementing these methods enhances the efficiency of food production by improving both its quality and quantity, as well as optimizing the utilization of essential resources like irrigation.

Combining this with the resurgence of urban agriculture, which has gained significant popularity and attracted the interest of numerous researchers, may be the most effective approach to mitigate the forthcoming food crisis. This theory is associated with the notion of intelligent irrigation systems that is employed in this study. Intelligent irrigation systems are defined by the integration of artificial intelligence into automated irrigation systems. This can be achieved by employing advanced control techniques, like as fuzzy logic or neural networks, to enhance the process of determining irrigation decisions. Alternatively, a substantial volume of data might be integrated into the analysis to improve irrigation models or control. This paper employs techniques such as deep learning and machine learning. The objective of intelligent irrigation systems is to enhance agricultural productivity while concurrently reducing the environmental impact of crops. This is achieved by providing irrigation to a crop at the optimal timing, in the optimal quantity, and at the optimal place.

Smart Irrigation Systems:

A. Soil moisture sensor
B. Weather based irrigation controllers.
C. IoT
D. Machine learning
E. Variable rate irrigators

3.2 Device for Measuring the Amount of Moisture Present in Soil:

Several techniques can be used to measure soil moisture sensors, including as gravimetric, tensiometer, neutron, γ-ray projection, remote sensing, and dielectric approaches.

3.2.1 The weight technique:

The weight technique refers to the process of drying. In order to reduce errors, it is typically necessary to calculate the arithmetic mean of parallel measurements two or three times, which actually grows as the workload extends the measurement duration. The microwave oven baking method not only saves time but also meets the specific criteria of the error, making it a more appropriate choice for the drying method (Shi Z *et al*, 2011). The drying method is the predominant approach employed to ascertain the moisture content of soil. Due to its simplicity, ease of execution, and satisfactory accuracy, this method serves as the fundamental methodology for assessing soil moisture and serves as the foundation for evaluating and comparing alternative methods. Nevertheless, there are notable drawbacks associated with this method, namely, it requires a substantial amount of time and effort, necessitates a lengthy measurement interval, and is unsuitable for the continuous and real-time monitoring of soil moisture at a specific location (Su S L *et al*, 2014).

3.2.2 Tensiometer:

The tensiometer method allows for the calculation of the energy stored in soil moisture by tracking the movement of water in porous objects that are in contact with the soil. The sensors employed in this technique typically comprised of a pair of electrodes placed within a cylindrical particle matrix that is submerged in the soil. The particle matrix maintains soil water equilibrium by facilitating the transfer of water from the surrounding soil. The moisture content in the sensor was quantified by monitoring the variation in electrical resistance between the two integrated electrodes. Particle matrix sensors are extensively utilized in large-scale deployments because of their affordability. Nevertheless, the tensiometer sensor's drawback lies in its restricted spatial variability, resulting in a notable lag and elevated maintenance expenses (Chow L. *et al*, 2009).

Benefits:

- Affordable.
- Resistant to salinity.
- Comes in various lengths.

Drawbacks:

- Limited operational range - inadequate for soils with a fine texture (0-90 kPa).
- Delayed reaction to fluctuations in soil moisture.
- Regular maintenance is necessary.
- Are not resistant to low temperatures.
- Manual data acquisition and collecting.

3.2.3 The Neutron Probe Method:

This technique involves the burial of the neutron source within the soil under examination. Fast neutrons are emitted constantly from the source and penetrate the soil, colliding with different atomic ions present in the medium. Afterwards, the fast neutrons dissipate energy and slow down the atoms. Fast neutrons have significant energy loss and readily decelerate upon colliding with hydrogen atoms. As the soil's moisture content rises, the hydrogen content and density of slow neutron clouds also increase. The neutron meter measures the moisture content in the soil by establishing the correlation between the density of the slow neutron cloud and water molecules. The neutron probe is employed to quantify the moisture content of soil, without causing any disturbance or disruption to the soil structure. It allows for continuous monitoring at specific locations, enabling the acquisition of real-time data on the movement of soil moisture. This method is both rapid and precise, and does not exhibit any hysteresis. Nevertheless, the utilization of the neutron instrument results in noticeable disparities between the indoor and outdoor curves. The distinct characteristics of soil in the field, such as varying bulk densities and soil textures, will induce more substantial deviations in the curve. Research has indicated that the vertical resolution of the neutron instrument is inadequate, making it difficult to accurately detect the surface layer. Furthermore, the neutron instrument is prohibitively costly, mostly due to the potential health risks associated with radiation exposure, making it impractical for widespread implementation (Gardner W *et al*, 1952).

Benefits:

- Precise measures.
- Collects specimens from a significantly expansive region.
- A universal sensor capable of measuring at all locations and depths.
- Resistant to the effects of saltiness and the presence of empty spaces surrounding the access tube.

Drawbacks:

- Calibration tailored to the soil or site is typically necessary.
- Costly
- Includes radioactive substances (poses a safety risk). Mandatory licencing is necessary.
- Manually read and record information, which takes around 3 minutes each access tube.
- Inadequate performance in shallow depths

3.2.4 Gamma-Ray Method:

The Gamma-ray (γ-ray) transmission method utilizes a radioactive source, such as 137Cs, to release γ-rays. These γ-rays pass through the soil and are detected by a probe, which converts the energy of the transmitted γ-rays into soil moisture content. The γ-ray and neutron instrument techniques offer various benefits, including rapidity and precision, preservation of soil integrity during measurements, and uninterrupted fixed-point monitoring.

However, the vertical resolution of the γ-ray approach is superior when compared to that of the neutron device. Additionally, the method's applicability is restricted due to certain safety considerations, making it cumbersome (Zhang L R and Qiao J, 2012).

3.2.5 The Method of Remote Sensing Using Infrared Radiation:

The soil moisture remote sensing approach utilizes the transmission or reflection of electromagnetic waves to measure the properties of the soil surface. This method is an efficient way to gather information on soil moisture on a regional scale (Yang T, *et al*, 2010 and Yin Z *et al*, 2000).

Benefits:

- The method enables the collection of measurements at a distance.
- Facilitates the acquisition of measurements across a vast expanse.

Drawbacks:

- The system is both extensive and intricate.
- Expensive
- Typically employed for topsoil.

3.2.6 Dielectric Method:

The dielectric constant of soil is influenced by various factors including electromagnetic frequency, temperature, salinity, volumetric water content, ratio of bound water to total soil water content, density, particle shape, and moisture form.

Since the dielectric constant of water in soil is more significant than that of other substances and air, it primarily relies on the water content of soil. Consequently, measuring the water content of soil can be achieved by determining the dielectric constant.

The study conducted by Chernyak in 1964, which gained global attention and was considered the first academic research on the dielectric properties of soils, revealed that soil, being a medium with considerable space, consists of solids, water, and air.

The dielectric constants of solids, water, and air are approximately 4, 80, and 1, respectively. Moreover, the dielectric constant of moist soil is primarily influenced by its water content. Therefore, utilising the dielectric properties of soil to determine its water content is an effective, rapid, straightforward, and dependable method (Dean T J, *et al*, 1987).

More precisely, it can be categorised into measurement techniques that rely on the principles of capacitance, resistance, time domain reflection, frequency reflection, and standing wave. Consequently, various varieties of soil moisture sensors have been created. The market offers three prevalent soil moisture sensor products: Time-Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), and Standing Wave Ratio (SWR).

A. TDR Soil Moisture Sensor:

The TDR soil moisture sensor is grounded on the study completed by Fellner-Feldegg *et al*. in 1969. The measurement technique for determining the soil dielectric constant was devised by leveraging the physical phenomena that the propagation velocity varies with the dielectric constant of the medium. In 1975, Topp *et al.*1980 pioneered the application of a method for studying soil moisture measurement.

Figure 3.1 displays the simplified representation of the sensor model. The signal generator produces a pulse signal. When this signal is sent to the probe through the coaxial wire, there is a mismatch in impedance.

A portion of the signal is reflected back along the same path, while the rest of the signal continues to be transmitted alongside the probe. During the investigation, there is a recurring occurrence of impedance mismatch at this particular moment. The detecting device is used to measure the time difference between the two reflected signals, which is the time it takes for the signal to travel twice along with the probe (Zazueta F S and Xin J N, 1994)

Benefits:

- Highly precise
- Soil/site calibration is typically unnecessary.
- Data can be accessed remotely.
- Drawbacks
- Extremely limited sphere of influence
- Costly technology

B. FDR Soil Moisture Sensor:

The FDR-type soil moisture sensor is derived from the theoretical research completed in 1992 by Hilhorst *et al.* 1995, from the Wageningen Agricultural University. A technique known as frequency domain decomposition was suggested as a means of quantifying the moisture content of soil, following the implementation of multiple research projects. This device is utilised to measure the amount of moisture in the soil and the resulting change in frequency induced by variations in the sensor's properties due to changes in the soil's dielectric constant. The FDR has greater flexibility than the TDR with regards to probe geometry length and operating frequency. Figure 3.2 depicts the streamlined representation of the sensor. During the measuring process, the soil functions as a dielectric, while the sensor's probe acts as both a capacitor and an external oscillator, so creating a tuning circuit.

The sensor's capacitance is directly proportional to the dielectric constant of the medium being measured between the two levels. The rise in moisture levels will concurrently augment the equivalent capacitance of the sensor, hence impacting the operational frequency (resonant frequency) of the sensor. The high-frequency oscillator emits signals with frequencies ranging from tens to hundreds of megahertz, and the high-frequency detecting circuit can detect the resonance frequency.

C. SWR Soil Moisture Sensor:

The alteration in the dielectric constant of the three-state mixture might result in a substantial modification in the standing wave ratio (SWR) of the transmission line. In 1996, Gaskin and Miller introduced a technique for measuring soil moisture that relies on the notion of Soil Water Retention (SWR) in the field of microwave theory. The measurement mechanism of this device is analogous to that of the Time Domain Reflectometer (TDR). However, instead of quantifying the time difference (ΔT) between the two signal reflections, it measures the Standing Wave Ratio (SWR) of the standing wave. Due to its greater technological feasibility, this sensor has a significantly lower price compared to the other two sensors. However, it does exhibit slightly lower measurement accuracy and sensor interchangeability. Figure 3 depicts the simplified representation of the sensor model. The signal source produces a 100 MHz signal.

However, when this signal is sent over the coaxial cable to the probe, there is a mismatch in impedance. When a portion of the signal is bounced back along the same path, the incoming and reflected signals combine to create a standing wave. The alteration of the voltage difference is directly influenced by the variation in the probe impedance, which is governed by the dielectric constant of the soil (Zhao Y D *et al*, 2016).

3.3 Weather Based Irrigation Controllers:

Controllers for irrigation systems that are designed to adjust watering schedules dependent on weather conditions. Weather-based irrigation controllers, referred to as smart irrigation controllers or ET (evapotranspiration) controllers, are advanced technologies that aim to enhance water efficiency in agriculture by customising irrigation schedules based on current weather conditions. These controllers utilise weather data, soil moisture levels, and plant requirements to generate accurate irrigation schedules, ultimately enhancing water efficiency, preserving resources, and raising crop yields.

3.3.1 Essential Elements and Operational Features:

A. Meteorological Sensors:

Weather-based irrigation controllers utilise a network of weather sensors to gather data on temperature, humidity, wind speed, and solar radiation. These sensors offer instantaneous data, enabling the system to make precise modifications to irrigation schedules according to present weather conditions.

B. Evapotranspiration (ET) Data:

Evapotranspiration (ET) is the collective term for the process in which water evaporates from the soil surface and transpires from the leaves of plants. Weather-based controllers employ evapotranspiration (ET) data to estimate the quantity of water that is lost from the soil and plants. This information is used to generate the most suitable irrigation schedule for replenishing these losses.

C. Devices for Measuring the Level of Moisture in Soil:

Soil moisture plays a crucial role in the control of irrigation. Weather-based controls commonly use soil moisture sensors to gauge the moisture levels in the soil. This data facilitates the system's comprehension of the current moisture levels and mitigates excessive irrigation, so guaranteeing that crops receive the appropriate quantity of water.

D. Technologies for Communication:

These controllers frequently utilize wireless connection technology to receive real-time weather updates and relay directives.

This facilitates the smooth incorporation of weather stations, satellites, and online databases, guaranteeing that the system is consistently refreshed with the most recent weather data.

3.3.2 Advantages of Weather-Based Irrigation Controllers:

A. Efficient Use of Water:

The main benefit of weather-based irrigation controllers is their capacity to conserve water. These controllers minimize excessive watering and minimize water wastage and related expenses by adapting irrigation schedules according to current weather conditions and plant requirements.

B. Energy Conservation:

Optimizing irrigation scheduling not only preserves water but also results in energy conservation. Conventional watering systems that adhere to predetermined schedules may consume excessive amounts of energy. Weather-based controllers enhance irrigation timing, resulting in decreased energy usage and the promotion of sustainability.

C. Enhanced Agricultural Productivity and Crop Resilience:

Customizing irrigation to suit the precise requirements of crops improves their overall vitality and efficiency. Excessive irrigation or insufficient watering can have a detrimental effect on plant growth and productivity. Weather-based controllers optimise irrigation by precisely regulating the amount of water crops receive, resulting in enhanced vitality and increased crop yields.

D. Expense Reduction:

Although the upfront investment of weather-based irrigation controls may be greater, the subsequent cost savings over time are substantial. Decreased water and energy usage, coupled with enhanced crop productivity, contribute to a more economically efficient and environmentally sustainable agricultural enterprise.

3.3.3 Disadvantages

A. Initial Expenses:

For certain farmers, the expense of installing weather-based irrigation controllers can provide a hindrance. Nevertheless, numerous governments and organisations provide incentives and subsidies to promote the adoption of water-efficient technologies.

B. Precision of Data:

The precision of meteorological data is vital for the efficient operation of these devices. Regular calibration and maintenance of weather sensors are essential to guarantee accurate data collection.

C. Technological Literacy:

Training may be necessary for farmers to comprehend and operate these sophisticated devices. To tackle this difficulty, it is crucial to promote technological literacy and offer assistance in implementing technology.

Water Sense Labelled Water-Based Inkjet Printers

3.3.4 Water Sense Certified Weather-Based Irrigation Controllers (WBICs):

Water Sense designates WBICs that adjust irrigation schedules using evapotranspiration (ET) principles, which depend on weather circumstances and plant kind. Evapotranspiration (ET) refers to the combined amount of moisture that is released as water vapor from a plant's leaves (transpiration) and from the soil and plant surfaces (evaporation). WBICs with the Water Sense label utilize information about the landscape (such as plant kind, soil type, slope) and local weather to create or modify irrigation schedules. The system's watering schedule is determined by data obtained from either a weather sensor situated on the landscape, or a signal received from a nearby weather station. Consequently, WBICs autonomously decrease the duration or frequency of watering when there is a lower demand for water, usually during colder seasons or when there is ample rainfall.

Water Sense labelled Weather-Based Industrial Cooling (WBICs) are available in a diverse range of models, encompassing different price points, levels of sophistication, and capacities. Models vary in size, with some designed for modest residential landscapes and others capable of managing the watering systems of huge commercial landscapes. Stand-alone controllers have the ability to replace an existing controller or be put in a new irrigation system, as they possess all the necessary scheduling capabilities. Additional and supplementary devices establish a connection with conventional clock time controllers. These devices can be fitted to enhance an existing irrigation controller by adding the weather-based watering feature to the system. Additionally, they have the potential to be coupled with a contemporary clock timer controller that is compatible and can be integrated into a novel system or serve as a substitute for a controller in an already established system.

Water Sense also designates WBICs that may be affixed to a hose bibb rather than an entire system, so enabling weather-based control for landscapes with only one or two zones that are generally irrigated using micro irrigation methods, such as gardens, trees, or shrub beds. Users have the ability to programme their landscape features, similar to WBICs that regulate in-ground irrigation. This programming, when combined with weather data, ensures that plants receive the appropriate amount of water only when necessary. An essential component of labelled controllers is the source of their weather data, which might originate from onsite weather sensors and/or weather signals obtained from local weather stations.

3.4 IoT (Internet of Things):

The fusion of the Internet of Things (IoT) with machine learning is transforming the agricultural sector, namely in the improvement of irrigation systems. These technologies address urgent concerns such as climate change, scarcity of water resources, and the increasing demand for food production.

The Utilization of Internet of Things (IoT) Technologies in the Agricultural Sector:

The Internet of Things (IoT) deploys a network of sensors over agricultural fields to gather real-time data on vital variables such as soil moisture, weather conditions, and crop health. The Internet of Things (IoT) enables farmers to remotely monitor and control irrigation systems, providing them with valuable data-driven insights to facilitate informed decision-making.

The Internet of Things (IoT) technology works well with farming systems because it can turn physical things like pots, plants, moisture sensors, and irrigation valves into digital objects that can be viewed over the Internet. These things can be identified by their own unique names or labels. By using this method, these parts can be controlled or watched over the internet. This lets a plantation be managed from afar and makes the most of tasks that usually need a worker to be there, like watering, fertilising, and inspecting crops.

An innovative device called the Internet of Things (IoT) is making big changes in many fields, including agriculture. Adding IoT to irrigation systems requires a number of different technologies. These technologies make it possible to turn real parts into data and make it easier to collect and combine data from sensors.

Either the cloud or other integrated systems can send and receive data. Embedded systems are specialised computer systems that are built to do specific jobs inside a machine or a bigger electrical system. In the future, cheap circuit boards like Arduino and Raspberry Pi could be used to process data, monitor systems, and run irrigation systems for data transfer. The way that IoT is being used in different systems for irrigation shows a lot of variation. One example is an Internet of Things (IoT) system that uses real-time tracking of variables and is built into a mobile app. In addition, a fuzzy logic-based controller is created and built for an automated irrigation system. Also, use advanced irrigation devices that use both fuzzy logic and the Internet of Things (IoT). What makes them different is that the second one also fertilises other plants.

The anti-frost irrigation device uses an Adaptive Neuro-Fuzzy Inference device (ANFIS) and the Internet of Things (IoT) to work. A neural network model is used in the study to predict what the temperature inside the greenhouse will be. A fuzzy logic method is also used to make sure that irrigation happens at the best time to protect crops from frost damage. A Convolutional Neural Network (CNN) and the Internet of Things (IoT) are both used in a different study project. Machine vision technology is used by this system to look at the plant's real state. It uses this information along with data on temperature, relative humidity, and soil wetness to figure out the best time to water. It is suggested that Machine Learning (ML) and the Internet of Things (IoT) be used to create an irrigation system that works with temperature, relative humidity, pH, and soil moisture as factors. In addition, the system predicts which crops will do well based on the land and weather, so that losses before harvest are kept to a minimum. The piece shows how IoT technology can be easily combined with other technologies to make monitoring and gathering data from sensors easier for future regulatory needs.

An interconnected system of sensors leveraging the Internet of Things (IoT) and big data produces a significant volume of data that grows rapidly as time progresses. Therefore, it requires the use of non-traditional computer processing tools to efficiently manage the data. For example, it is used to supply water to an open field crop and to assess three machine learning techniques for predicting soil moisture. These models utilise a fuzzy logic approach to control irrigation. Likewise, the crop irrigation system employs a machine learning algorithm. Moreover, an Internet of Things (IoT) platform is utilised to establish a link between the physical devices of the system and a mobile application, enabling the display of specific data. Artificial intelligence technique that allows computers to learn and make predictions or decisions without being explicitly programmed.

3.5 Machine Learning (ML):

The utilisation of machine learning (ML) in agriculture is exceedingly beneficial since it enables computers to gather insights from current data. This includes a variety of meteorological factors that are continuously recorded by weather stations, as well as measures collected from continuous crop monitoring. Machine learning leverages this data by utilising it as input for mathematical algorithms that aim to predict or categorise a certain variable of interest. For instance, the evapotranspiration value can be utilised to calculate the necessary irrigation durations for the crop. Machine learning algorithms exhibit a wide range of diversity, and their categorization into distinct sub-domains is determined by their specific application and amount of intricacy. The analysed articles provide examples of the pragmatic application of irrigation systems. The method suggests employing Artificial Neural Networks (ANN) to forecast soil moisture within a one-hour timeframe from the moment of measurement. Furthermore, this system employs a feed-forward neural network approach, which is a grading algorithm that draws inspiration from biological processes.

The algorithm's training is optimised through the utilisation of gradient descent and variable learning rate gradient descent. These techniques address optimisation problems by iteratively utilising first-order derivatives. Similarly, it suggests comparable systems, but with the utilisation of the potent back propagation and scaled conjugate gradient optimisation techniques.

Different research utilised an Artificial Neural Network (ANN) model to precisely predict soil moisture levels during the upcoming hour. Additionally, the forecast is evaluated in comparison to the desired soil moisture level, and the discrepancy is utilised to regulate irrigation. The radial basis function model, an artificial neural network technique, is employed in this case to align functions. Moreover, it employs a system that utilises the K-nearest neighbour (KNN) ranking algorithm to forecast the optimal timing for irrigation. This method utilises the initial data obtained from four different soil conditions, ranging from dry to wet, to compare it with the recently collected data from the sensors of the system. Afterwards, it uses this assessment to offer knowledgeable recommendations regarding irrigation.

Researchers suggest using a machine learning decision tree algorithm to generate a warning suggesting the optimal time for watering. This concept is derived from the hierarchical arrangement of a tree. The decision process starts with a primary node that represents a series of data divisions and progresses via various branches until it reaches a binary outcome. Studies suggest the use of a system that utilizes a traditional neural network algorithm to determine the optimal timing for irrigation, based on data collected from many sensors. Moreover, a supplementary study suggests an innovative irrigation method that seeks to ascertain the optimal period for watering. For this scenario, a random forest algorithm is employed, which entails the aggregation of several autonomous decision trees that are created to categories and forecast data. In essence, it utilizes a model that incorporates a refining process to the data by employing data fusion. Improved data quality is achieved by the use of a variety of sources. Subsequently, the collected data is utilized to train the DL support vector machine technology, which has been specifically designed for the purposes of data classification, regression analysis, and identification of anomalies. Another research endeavour utilizes an irrigation system that forecasts soil moisture levels by combining support vector regression (a machine learning approach akin to support vector machine) with K-means data clustering methods. A separate study employs various machine learning algorithms to determine which one has the highest level of accuracy in predicting soil moisture. The GBRT technique, also known as gradient boosting regression tree, achieves optimal outcomes by combining a collection of weak predictive models, usually decision trees, to generate a robust predictive model that can provide accurate forecasts for evapotranspiration.

Another experiment utilizes image processing algorithms to demonstrate the immediate effects of water stress on plants. This is achieved by conducting a comparative analysis of the physical characteristics of crop leaves prior to and following the irrigation procedure. The study introduces a control system that computes the optimal timing for watering. The DL long short-term memory (LSTM) algorithm is a component of the irrigation system. It possesses the capacity to acquire information regarding enduring associations, particularly in the realm of forecasting sequences. An autonomous study aims to enhance the efficiency of the irrigation system and provide recommendations on the most suitable crop for the upcoming crop rotation. Conversely, its aim is to forecast the soil moisture level for the following day. The central focus of all the systems evaluated in this context is the specific control mechanism utilized for the irrigation valves. The fuzzy logic system is responsible for overseeing irrigation regulation. The system gets inputs from the machine learning models, as well as other variables. The irrigation control is regulated by algorithms that utilize projected soil moisture values to ascertain the appropriate timing for initiating or terminating the irrigation system. The machine learning system independently manages the irrigation control. However, in a particular study, it triggers a notification to prompt the cultivator to initiate the irrigation process. The goals for incorporating machine learning into irrigation systems vary throughout the published studies.

3.5.1 The convergence of Internet of Things (IoT) and Machine Learning:

The synergy between IoT and machine learning is especially powerful in the context of irrigation systems. The data collected from IoT sensors is used in real-time to train machine learning models, allowing for prompt and well-informed decision-making. This dynamic strategy guarantees that irrigation practises adapt to the present condition of the agricultural environment, fostering efficiency and the preservation of resources.

The combination of IoT and machine learning represents a significant period of change in agriculture, improving the accuracy and effectiveness of irrigation while tackling the intricacies of contemporary farming. Through the use of connectivity, data analytics, and adaptive learning, farmers are equipped with the ability to effectively address obstacles and make valuable contributions towards a more sustainable future for worldwide agriculture. The integration of IoT and machine learning in irrigation showcases the capacity of technology to transform conventional methods and address the needs of a swiftly changing agricultural environment.

3.5.2 The utilization of Internet of Things (IoT) and intelligent technologies in the field of irrigation:

A. Technologies Related to The Transmission and Exchange of Information:

Choosing the right communication method is very important for setting up IoT devices correctly. How people use communication tools can be affected by the setting in which they are used (S. Ghosh et al., 2016). The main IoT technologies used for watering can be broken down into two separate groups. The devices that can be thought of as nodes and can send or forward small amounts of data over short distances while using only a small amount of power. Because of this, the other devices can send large amounts of data over long distances while using a lot of power. IoT devices can use different wireless standards, which can be roughly grouped by how well they can talk to each other over long or short distances (A.T. Abagissa et al., 2018). People agree that Wi-Fi is one of the best and most popular ways to communicate, mostly because it is easy for many people to access. New study shows that most of the cheap IoT devices on the market right now only support Wi-Fi. Wi-Fi has some problems, like a small service area and limited reach, but it is generally thought to be a good solution (M. Soto-Garcia et al., 2013). It is also known that the Global System for Mobile Communication (GSM) is a widely used wireless system that lets people talk to each other over long distances. All you need is a mobile plan from a service provider that works in that area. This year, Long Range (LoRa) and Message Queuing Telemetry Transport (MQTT) have become two of the most important new technologies. LoRa has a wide range of service, which makes it a great option for remote areas that don't have any other way to connect. MQTT is not often used for watering systems right now, even though it has low costs and uses little power (M.S. Munir et al., 2019).

B. Cloud Computing Technologies:

Cloud storage and standard databases are two of the most important and widely used types of storage. Because they let businesses keep and get back important data when they need to, these storage systems are necessary in many fields and industries. Big data, which is when companies use very large numbers for different reasons, has become easier thanks to storage systems (M. Monica et al., 2017). People who use the Internet of Things (IoT) need to use software to get the services they need. Utilising middleware makes it possible to connect products that weren't created to work together in the first place. IoT middleware is also put into groups based on its features and its ability to work with different interaction protocols (M. Roopaei et al., 2017). There are a lot of sensors in agriculture, especially in irrigation systems, that store and analyse data. The cloud is very important in this process. Several studies have found that data processing takes place in the cloud, and people can get to the data by connecting to the cloud. The main way that cloud technology is used in irrigation is to store and then get back monitoring data (S. Salvi, et al., 2017). People can store, view, and show their data on a variety of devices and platforms with cloud technology. There are both paid and free options available. Using this technology to store information related to work makes total performance much more efficient. People use the stored data for many things, including study and development, which is seen as an important use. Many agricultural companies can now keep and access data more easily thanks to cloud technology, which has also made their operations more efficient and effective. Cloud technology has been used to build systems that send alerts during the irrigation process. Many dangers and threats that could have happened otherwise have been avoided with these alerts. When you use these signs, it's easier to change how you do your job and put in place the necessary steps to avoid problems. In the area of cloud technologies, many programmes have been made to help people do their jobs better. Each of these programmes is important and serves a different purpose. How they are put into action relies on things like cost, usefulness, services, and other factors. The irrigation system could be seen as a complicated job that needs to be done while taking into account the risks, losses, and difficulties that come with it. Staff members who work in irrigation use cloud technologies to lower risks and improve work results, which helps them reach their goals.

C. Advantages of Implementing an Internet of Things (IoT) Technology in Irrigation:

Using IoT systems in irrigation has many benefits, such as using less water generally, saving money, making things work better, using less energy, wasting less food, and more (L. García et al., 2020). In irrigation, one of the best things about IoT devices is that they can cut down on water use. This method also automates most of the work that needs to be done for watering, which makes sure that the right amount of water is used and that as little as possible is lost. A lot of water was wasted during the irrigation process with old ways that required a lot of manual labour (K. Jha et al., 2019). Smart irrigation reduces the need for human involvement and makes the best use of water by only using what is needed. Along with these benefits, it's important to note that this technology is also very cost-effective. Because less water is used and the process is done correctly, costs are cut and overall expenses go down. The approach drastically lowers energy use by limiting machine runtime and putting in place set intervals, which leads to lower overall energy use.

Also, because resources are limited, businesses have to limit their spending to a certain point. It is very important to keep costs down and use resources wisely. Smart irrigation takes cost into account, allowing linked jobs to be done efficiently and with lower costs. Another benefit is that better irrigation and water management make sure that plants and crops only get the water they need, which reduces yield loss caused by too little or too much water intake.

3.6 Variable-Rate Irrigation (VRI):

Variable-rate irrigation (VRI) is a cutting-edge technology that allows a centre pivot irrigation system to optimise the application of water. The lack of uniformity in most fields can be attributed to natural variances in soil type or terrain. When water is evenly distributed across a field, certain sections of the field may receive excessive water while other sections may experience insufficient moisture. Some farmers control these specific places by deliberately excluding them from the cultivated land. Nevertheless, VRI technology provides farmers with an automated approach to adjust the rates of irrigation water according to the specific management zones within a field. A VRI system offers a straightforward and automated solution to prevent the irrigation of streets, streams, wetlands, and other non-farmed areas within a pivot. A VRI system has the capability to be installed on current centre pivot systems and operates by incorporating GPS positioning into a control system. The control system sequentially activates individual sprinklers or groups of sprinklers, regulating their operation and adjusting travel speed to attain the appropriate application rates in distinct management zones.

A Variable Rate Irrigation (VRI) system comprises a centre pivot irrigation system integrated with the following components:

- Individual sprinklers are equipped with electrically or pneumatically/hydraulically operated valves.
- A controller is used to activate individual sprinklers or groups of sprinklers and to alter the speed at which irrigation is carried out.
- A motor controller, if desired, can be used to regulate the speed of the pump in order to prevent excessive pressure when a variable-speed pump is utilised.
- A GPS is used to determine the precise location of the system.
- An interface for users to perform field mapping and system configuration.

The management zones for Variable Rate Irrigation (VRI) are established by incorporating the farmer's field expertise, aerial imagery obtained from online sources, maps displaying the field's diverse characteristics such as soil electrical conductivity, yield, topography, and other relevant parameters, as well as soil water monitoring data.

Advantages In the Field of Agronomy:

A VRI system improves the farmer's capacity to customise water distribution based on the specific requirements of different crops throughout the field. By utilising a Variable Rate Irrigation (VRI) system, the farmer can enhance the accuracy of irrigation by aligning it with the individual characteristics of the soil types and topography of the site.

VRI is often applicable in domains characterised by significant diversity in soil composition and crop productivity. The agronomic advantages of Variable Rate Irrigation (VRI) are as follows: The utilisation of Variable Rate Irrigation (VRI) can result in enhanced agricultural productivity and improved crop quality due to the application of water in optimal and variable quantities.

- Reduced leaching and runoff of nutrients applied are observed.
- To minimise weed and disease issues, it is crucial to avoid excessive application of water when irrigation systems overlap.
- Obstacles and motivators for carrying out a plan

Advantages:

- The farmers' hesitance to introduce additional intricacy to their irrigation system
- Financial allocation for the purpose of generating profit or increasing wealth.
- Inadequate knowledge of such systems

Disadvantages:

- Minimization of water and energy consumption
- Versatility (may be implemented on virtually any system)
- Enhanced command over the operation of the irrigation system
- Enhancements in the management of nutrients and pests

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