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Irrigating with Intelligence: Sensor-Based Strategies for Efficient Agriculture – A review

Akash Paul[1], Hridesh Harsha Sarma[1], MrigankoKakoti[2], NilabhTalukdar[1], Saurav Kumar Dutta[1], Priyanka Hazarika[3] and Anwesha Goswami[4]

[1]Department of Agronomy, Assam Agricultural University, Jorhat 785 013, Assam, India
[2]Department of Agricultural Meteorology, Assam Agricultural University, Jorhat 785 013, Assam, India
[3]North Salmara Circle, Government of Assam, Bongaigaon 783 388, Assam, India
[4]Department of Horticulture, Assam Agricultural University, Jorhat 785 013, Assam, India

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ABSTRACT

Sensor-based irrigation scheduling is a cutting-edge technology transforming modern agriculture. It involves the use of diverse sensors, including soil moisture, weather, and crop sensors, to continuously monitor environmental variables and crop water needs in real-time. This data-driven approach enables farmers to make informed decisions regarding irrigation, leading to more efficient water utilization, reduced resource wastage, and increased crop yields. This study underscores the importance of sensor-based irrigation scheduling in achieving sustainable and precise farming practices. It highlights its potential to revolutionize traditional agricultural methods, promote water conservation, and ensure food security in a world facing evolving climate challenges and growing global food demand. This technology holds promise as a key driver of agricultural sustainability and productivity in the years ahead.

Key words: *Food security, Irrigation scheduling, Productivity, Sensors, Sustainability*

Introduction

For millennia, agriculture has been the foundation of human civilization, giving populations all over the world sustenance, livelihoods, and economic stability. However, as the population grows, nutritional habits change, and environmental problems like climate change arise, the demands on agriculture are constantly shifting. The effective and sustainable use of water resources in agriculture has become a top priority on a global scale in this dynamic environment. Modern sensors-based irrigation systems have become revolutionary tools for managing water for crop production, providing accuracy, efficiency, and sustainability. Traditional irrigation techniques are frequently characterized by inefficiency, excessive water use and negative environmental effects. Conventional systems, which rely on set schedules or human intuition, can result in under- or over-irrigation, which has a negative impact on crop yields, water conservation, and the general economic viability of farming operations. These restrictions have sparked the creation and uptake of contemporary sensors-based irrigation technology, ushering in a new era in agricultural water management. By integrating the modified Penman-Monteith equation advised by the FAO along with GIS technology, irrigation water demand as well as

(M.Sc Scholar, [2]M.Sc Scholar, [3]Agriculture Development Officer, [4]M.Sc Scholar)

crop water requirements may be calculated (Duchenin *et al.,* 2006). As a result, a method for figuring out when to provide water to the crops is required. Modern sensors-based irrigation is built on the deployment of a wide variety of sensors that keep an eye on vital indicators in the continuity of soil, plants, and atmosphere. These sensors collect real-time information on the state of the crops, weather, soil moisture levels, and other pertinent variables. Making informed judgements about when, where, and how much water to apply is done using the data that has been gathered. The installation of a large number of soil moisture sensors that can accurately depict the natural soil moisture variability prevalent in any field is made possible by the sensor nodes' comparatively low cost. This method would lighten the farmer's labour and assist in maintaining healthy soil conditions for increased crop output. Therefore, with the development of technology, it is now possible to build systems that do not require the farmer to be directly involved in the watering of their fields (Chandrika *et al.,* 2012). There are a number of approaches that may be used to determine the soil moisture content (in volumetric and gravimetric forms), which can be divided into (i) classical and (ii) current procedures for both the laboratory and in situ measurements. Thermogravimetric, calcium carbide neutron scattering, gypsum block, and tensiometer procedures are a few examples of traditional soil moisture monitoring methods. While more recent methods make use of tensiometers, soil resistivity sensors, infrared moisture balance, dielectric techniques such as Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), capacitance technique, heat flux soil moisture sensors, micro-electro mechanical systems, and optical methods (Blonquist *et al.,* 2006). The ability to irrigate according to a crop's specific needs in a given field may be made possible by soil moisture sensors. These sensors can be used in conjunction with the FAO approach, as a "stand-alone" method, or to supplement irrigation management based on experience (Thompson *et al.,* 2007). Fig. 1 represents a distributed in-field Wireless Sensor Network's (WSN) notional system layout. The system consists of numerous parts, often known as "nodes." The nodes are intelligent gadgets that are used to gather the data necessary for application-oriented systems. Utilising hardware, software, and algorithms, a sensor network may carry out the following three fundamental tasks: sensing, communication, and computation. The nodes play a number of roles. Source nodes are the scattered nodes that acquire data, whereas sink nodes or gateway nodes are the nodes that compile data from all source nodes. The sink node might have a sizable amount of processing power. Due to the necessity of multi hop routing, a source node also functions as a rout-

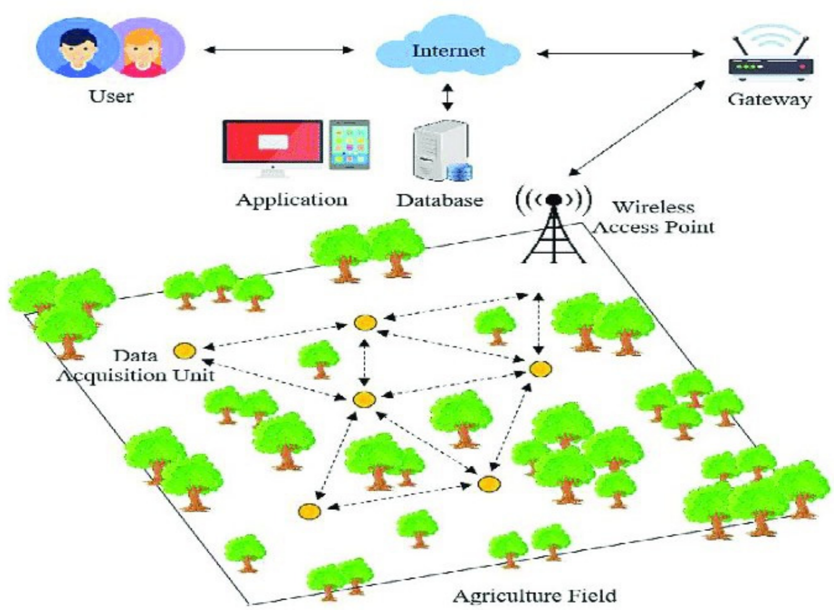

Fig. 1. Showing wireless sensor network for automated irrigation. Source: (Li *et al.,* 2020)

ing node. An optional module that can be required if data storage is needed for regional decision-making is external memory. The field sensors keep an eye on the temperature, moisture, and temperature of the soil. Wireless transmissions of all in-field sensory data are made to the base station. The base station delivers control instructions to the irrigation control station after processing the in-field sensory data through an intuitive decision-making programme (Abbasi *et al.*, 2014). Thus, with this system, farmers can receive real-time data from their farms such as soil moisture, crop growth etc. *via* an Android app or automatic SMS service, allowing for better crop management techniques. The farmers might be guided on when and how much to irrigate using this information.

Automated Irrigation system: The need of the hour-

(1) Simple system installation on the pitch.
(2) Energy and resource savings for accurate use.
(3) In automated irrigation systems, valves are used to turn on and off the engine.
(4) Applying the appropriate amount of water at the appropriate time to make it easier for the farmer to manage farm irrigation and nursery.
(5) Sensor-based controllers make it simple to manage a pump or motor, eliminating the need for manual labor to run or maintain irrigation systems.
(6) Crop efficiency involves a reduction in overwatering due to saturated soil and avoiding irrigation at the wrong time to conserve water.

Different types of sensors required for Automated Irrigation system

Agriculture is a rapidly advancing field, necessitating the integration of various sensors for effective monitoring and control. These sensors include soil moisture sensors, humidity sensors, temperature sensors and ultrasonic sensors. The data collected by these sensors is linked to an Arduino UNO for processing. In the control section, the collected data is analyzed against predefined threshold values. When the humidity level falls below a certain threshold, the Arduino activates a water pump to irrigate the system. The water pump automatically stops when sufficient humidity is detected in the soil. Simultaneously, an electronic message is sent to the end-user through the IoT (Internet of things) section, providing information about soil moisture levels and the status of the water pump. These factors also play a role in addressing pest infestations, which can be managed by applying the appropriate pesticides. The irrigation system has been designed to efficiently control water distribution and pesticide spraying on farms or fields. Parameters such as humidity, temperature, and moisture are continually monitored using sensors. Pesticides and water are applied using a spray machine and a motor-pump. An ultrasonic sensor is employed to monitor plant growth, allowing users to remotely observe their plants through a web page via IoT. Currently, Think Speak, a system compatible with iOS (i-Phone Operating System), is utilized to control Arduino and manage the electronic hardware. This system not only facilitates plant growth monitoring through the ultrasonic sensor but also enables the transmission of data to a web page through the IoT module (Li *et al.,* 2020). Irrigation is carried out automatically according to a predefined schedule.

Soil moisture sensors

The soil moisture sensor allows for the evaluation of soil moisture content. When a soil moisture input from a sensor exceeds a threshold, the low level (0 V) will be the digital result, and if it falls below the threshold level, the higher level (5 V) will be the digital result. If the current soil moisture input is greater than or less than a threshold, a digital pin can be used to read it directly.

Watermark 200SS sensors

This sensors measures electrical resistance inside a granular matrix to calculate soil water tension. Typically, a voltage divider circuit is employed to measure resistance inside the sensor. To determine the value of another resistor (the sensor), the circuit employs a known input voltage, output voltage, and series resistor value.

DHT11 sensors

The DHT11 sensor instrument is capable of calculating humidity and temperature. It measures air pressure using a thermal resistor and capacitive humidity sensor. This sensor is inexpensive, uses minimal energy, and enables signal transmission up to 20 meters.Top of Form

Ultrasonic sensors

A probe consists of a particular cable that is capable of accurately measuring the surface level of practically all fluids, including water, oils, and saltwater. An electrically isolated sensor component that is likewise insulated from the tissue in which it is implanted will not diintegrated over time.

Capacitance sensors

The solids, gases, and liquids that make up soil have the ability to hold electrical charge. The dielectric constant is a term used to describe electrical charge. Although the dielectric properties of liquids, gases, and soils vary, it is simple to distinguish between water and other substances. Water has the biggest electrical charge, which makes it clear when the soil becomes dry, which is why this kind of soil moisture sensor is so useful. So that farmers can act swiftly when decreasing moisture levels are detected, the software immediately notifies the user. Connecting a capacitance sensor and receiving readings on a phone, tablet, or laptop is simple. Farmers can determine whether the crops need water without being present at the location. They are affordable and simple to install.

Flow sensors

Flow sensors and flow metres keep an eye out for any indication that the irrigation system is using too much water. This sensor will avert an irrigation system malfunction if the crops don't require so much water. A flow sensor will warn the person in charge of the water system and stop any damage. The sensor will alert the person in charge of the situation and prevent the controller from starting another water cycle. Farmers can identify potential damage without being physically there by using flow sensors.

Rain sensors

Using the proper amount of water to irrigate the soil is one of precision irrigation's best benefits. Some of the earliest irrigation sensors were rain sensors, and they will continue to be used. The sensors will halt the subsequent watering cycle once rain is detected. Farmers have the ability to dramatically reduce their water use based on the amount of rain that is received. The newest rain sensors work by expanding discs that are submerged in water. They flip the valve, stopping the irrigation cycle until the expanding discs are dry once more. Farmers can conserve resources while still achieving the greatest outcomes thanks to the robustness, simplicity, and effectiveness of these sensors

Freeze sensors

When the outside temperature drops below 32° F, these sensors stops a watering cycle. Eliminating irrigation during freezing conditions may increase the lifespan of irrigation systems and avoid dangerous circumstances caused by icing over pavements and streets (Gotcher *et al.,* 2014).

Wind sensors

When the wind speed reaches a specific level, wind sensors halt the watering cycle. Farmers will use less water as a result of using wind sensors because water will only flow under ideal circumstances when there is no wind. Farmers can profit from adding wind sensors to their current irrigation system.

Beside these, there are several numerous sensors implemented in order to manage effective need based irrigation scheduling (Table 1).

Table 1. Examples of sensors used in irrigation scheduling

		Soil						
Sl. No.	Sensors	Temperature	Moisture	Dielectric permittivity	Rain	Water level	Conductivity	Salinity
1.	Pogo portable soil sensor	√	√	√	√	–	√	–
2.	Hydra probe II soil sensor	√	√	√	√	√	√	√
3.	ECH2O soil moisture sensor	√	√	√	–	√	√	–
4.	MP406 Soil moisture sensor	√	√	√	–	–	–	–
5.	EC sensor (EC250)	√	√	–	√	–	√	√
6.	ECRN-100 high-REC rain gauge	–	–	–	√	–	–	√
7.	ECRN-50 low-REC rain gauge	–	–	–	√	–	–	√
8.	107-L temperature Sensor (Beta Therm 100K6A1 BThermistor)	√	–	–	–	–	–	√

Source : (Abbasi *et al.,* 2014)

Methods of accquiring data in sensor-based irrigation scheduling

Data acquisition in sensor-based irrigation scheduling is a multifaceted process crucial for efficient and sustainable agricultural practices. This mechanism involves deploying various sensors strategically throughout the field to gather real-time information on soil, weather, and plant conditions. Soil moisture sensors assess moisture levels at different depths, while weather stations record temperature, humidity, wind speed, and solar radiation. Additionally, specialized plant health sensors might monitor leaf wetness, canopy temperature, or stress indicators.

Once collected, this data is transmitted wirelessly to central controllers or cloud-based platforms, facilitating instant analysis and informed decision-making. The data is then stored for historical reference, enabling trend analysis and long-term planning.

Integration of data from diverse sensors allows for a comprehensive view of field conditions. Advanced algorithms and models are applied to this data to determine irrigation requirements. For instance, soil moisture data helps assess if the soil is parched and in need of watering, while weather data predicts rainfall and evapotranspiration rates.

The irrigation system controller uses this analyzed data to adjust schedules, durations, and zones requiring watering. Actuators receive control commands to initiate or modify irrigation cycles based on data-driven decisions. Real-time monitoring ensures the system remains responsive to changing conditions, and users can access the system through user-friendly interfaces to view data, schedules, and system status. Ultimately, data acquisition in sensor-based irrigation scheduling optimizes irrigation, conserves water, enhances crop health, and promotes sustainable agriculture.

Benefits of sensor based irrigation

1. Real-time measurements of soil moisture, weather, and plant water requirements are possible with sensor-based irrigation systems. This knowledge enables accurate and effective watering, lowering water waste and protecting this precious resource.
2. Sensor-based irrigation systems can help to maximise crop yield and quality by giving plants the appropriate amount of water at the appropriate time. Higher agricultural output and improved crop health may result from this.
3. Water, energy, and labour expenses can all be reduced by using precision irrigation systems. Farmers and landowners can save their operating costs by automating irrigation and reducing overwatering.
4. This system can benefit the environment by using less water and lowering runoff. They can aid in reducing soil erosion and water body contamination from excess nutrients and pollutants.
5. Consistent and optimal watering can promote better plant health and reduce stress on crops. This can result in stronger plants that are more resistant to pests and diseases.
6. Sensor-based irrigation systems are adaptable to the particular requirements of various crops, soil types, and environmental factors. It is possible to adjust irrigation strategies due to its flexibility.
7. Many sensor-based irrigation systems allow for remote monitoring and management via computers or cellphones. This enhances convenience and responsiveness by enabling farmers and landowners to change irrigation schedules and settings from any location.
8. By ensuring that the existing water resources are used effectively, sensor-based irrigation can help lessen the effects of droughts. It enables the distribution of scarce water supplies to places that most need them.
9. Ultimately, by optimizing crop yields, reducing costs, and conserving resources, sensor-based irrigation can contribute to increased profitability for farmers and landowners.

However,it is crucial to remember that sensor-based irrigation systems' efficacy depends on a variety of elements, including the calibre of the sensors used, the accuracy of the data collected, and the user's skill in deciphering and acting on the information provided by the system. Realising these advantages requires proper calibration, installation, and maintenance.

Conclusion

Sensor-based irrigation plays a crucial role in modern agriculture by maximizing crop yields, conserving resources, and promoting sustainability. As technology continues to advance, these systems are expected to become increasingly sophisticated and integrated into the broader landscape of precision agriculture. It represents a transformative shift in agricultural practices, offering a beacon of hope in a world grappling with water scarcity and the need for sustainable food production. By harnessing the power of advanced sensors, data analytics, and automated control, this technology allows us to irrigate with unprecedented precision. Through real-time monitoring of soil moisture, weather conditions, and plant health, sensor-based systems empower farmers to make informed decisions, delivering water precisely when and where it's needed. This not only conserves our most precious resource but also enhances crop yield and quality while minimizing the environmental footprint of agriculture. As the global population continues to grow, and climate change poses new challenges, sensor-based irrigation proves to be an indispensable tool in the modern farmer's arsenal. Its ability to adapt, conserve, and optimize resources makes it a key driver of sustainable agriculture, ensuring that we can nourish the world's population while safeguarding our planet's fragile ecosystems. In embracing sensor-based irrigation, we move towards a future where agriculture is not just productive but also environmentally responsible and resilient.

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