JETNR
Journal of Emerging Trends and Novel Research
JETNR.ORG | ISSN : 2984-9276
An International Open Access, Peer-reviewed, Refereed Journal

IoT-Based Smart Irrigation Systems: A Systematic Review*

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Abstract—
Water is one of the most valuable natural resources required for agricultural productivity and human survival. However, due to rapid population growth, industrialization, and climate change, the availability of freshwater resources is continuously decreasing. Traditional irrigation methods such as flood irrigation and manual watering systems are inefficient and lead to significant water wastage. These methods do not consider the real-time moisture condition of the soil, resulting in either over-irrigation or under-irrigation, which adversely affects crop growth and yield.

In order to overcome these challenges, this paper proposes an advanced Smart Irrigation System using Internet of Things (IoT) technology for efficient and sustainable water management. The system utilizes soil moisture sensors to continuously monitor the water content present in the soil. The collected data is transmitted to a microcontroller, which processes the information and determines the irrigation requirement based on predefined threshold values. When the moisture level falls below the required limit, the system automatically activates a water pump through a relay module. Once the optimal moisture level is achieved, the system switches OFF the pump, thereby preventing water wastage.

Furthermore, the proposed system can be integrated with wireless communication technologies to enable remote monitoring and control. This enhances the efficiency of the irrigation process and reduces the dependency on manual labor. The system is designed to be cost-effective, reliable, and scalable, making it suitable for both small-scale and large-scale agricultural applications. By optimizing water usage and improving crop productivity, the proposed smart irrigation system contributes significantly to sustainable agriculture and resource conservation.

Keywords—
Smart Irrigation, Internet of Things, Soil Moisture Sensor, Automation, Water Conservation, Sustainable Agriculture, Embedded Systems.

I. INTRODUCTION

Agriculture is the backbone of many economies, especially in developing countries where a large portion of the population depends on farming for

their livelihood. Water plays a crucial role in agricultural activities, as it directly influences crop growth, productivity, and overall yield. However, the increasing demand for water due to population growth and industrial expansion has resulted in severe water scarcity in many regions of the world.

Traditional irrigation techniques such as flood irrigation, sprinkler systems, and manual watering are widely used but are highly inefficient in terms of water utilization. These methods do not account for the actual moisture requirement of the soil and often lead to excessive water consumption. Over-irrigation can cause soil erosion, nutrient leaching, and waterlogging, while under-irrigation can result in poor crop growth and reduced yield. Therefore, there is a need for an intelligent irrigation system that can optimize water usage based on real-time conditions.

The emergence of IoT technology has revolutionized various sectors, including agriculture. IoT enables the connection of physical devices such as sensors and actuators to the internet, allowing them to collect and exchange data in real-time. By integrating IoT with irrigation systems, it is possible to monitor soil conditions continuously and automate the irrigation process. This not only improves water efficiency but also reduces human effort and operational costs.

This paper presents a smart irrigation system that leverages IoT technology to provide an efficient and automated solution for water management. The system is designed to monitor soil moisture levels and control irrigation accordingly, ensuring optimal water usage and improved agricultural productivity.

II. LITERATURE SURVEY

In recent years, several researchers have explored the application of IoT in agriculture to develop smart irrigation systems. Many studies have focused on the use of wireless sensor networks (WSNs) to monitor environmental parameters such as soil moisture, temperature, humidity, and light intensity. These systems aim to provide precise irrigation by delivering water based on the actual needs of the crops.

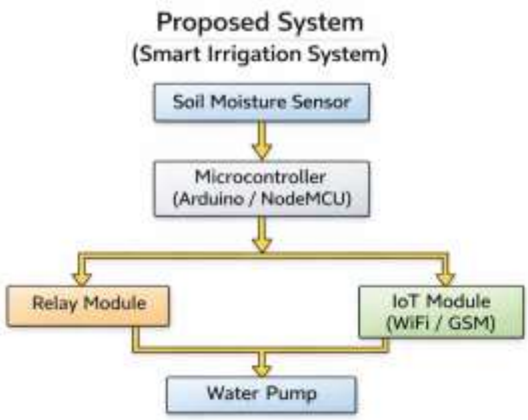
Some existing systems incorporate cloud computing and mobile applications to enable remote monitoring and control. Farmers can access real-time data and control irrigation systems using smartphones or computers. While these systems offer advanced features, they often involve high implementation costs and require technical expertise, making them less accessible to small-scale farmers.

Other research works have proposed low-cost solutions using microcontrollers such as Arduino and NodeMCU. These systems are relatively simple and cost-effective but may lack scalability and advanced functionalities.

The proposed system aims to strike a balance between cost, efficiency, and functionality. It provides a simple yet effective solution for smart irrigation that can be easily implemented and maintained. The system focuses on real-time monitoring, automation, and efficient water usage while minimizing complexity and cost.

III. PROPOSED SYSTEM

The proposed smart irrigation system is designed to automate the irrigation process using IoT technology. It consists of several key components, including soil moisture sensors, a microcontroller unit, a relay module, and a water pump. Each component plays a vital role in the overall functioning of the system.



The soil moisture sensor is responsible for measuring the moisture content in the soil. It continuously monitors the soil condition and generates analog or digital signals based on the moisture level. These signals are transmitted to the microcontroller, which acts as the central processing unit of the system.

The microcontroller processes the sensor data and compares it with predefined threshold values. If the moisture level is below the threshold, the microcontroller sends a signal to the relay module to activate the water pump. The pump supplies water to the soil until the desired moisture level is reached. Once the soil moisture reaches the optimal level, the microcontroller deactivates the relay, turning OFF the pump.

This automated system ensures that water is supplied only when required, thereby reducing wastage and improving efficiency. The system can also be expanded by integrating additional sensors and communication modules for enhanced functionality.

IV. SYSTEM ARCHITECTURE

The system architecture of the proposed smart irrigation system is divided into three main units: input unit, processing unit, and output unit.

A. Input Unit

The input unit is responsible for collecting real-time environmental data from the agricultural field. It mainly consists of soil moisture sensors, which are strategically placed in the soil near plant roots to measure the volumetric water content. These sensors operate by detecting changes in electrical conductivity or capacitance caused by varying moisture levels.

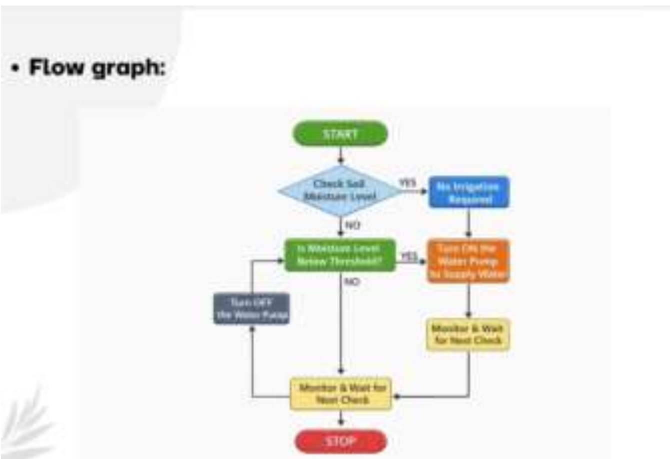
In addition to soil moisture sensors, the system can be extended to include other sensors such as temperature and humidity sensors to provide a more comprehensive analysis of environmental conditions. The data collected from these sensors is continuously transmitted to the processing unit for further evaluation.

B. Processing Unit

The processing unit acts as the brain of the system and is typically implemented using a microcontroller such as Arduino Uno or NodeMCU (ESP8266). This unit receives analog or digital signals from the sensors and processes them using embedded algorithms.

The microcontroller is programmed with predefined threshold values corresponding to optimal soil moisture levels required for crop growth. It continuously compares incoming sensor data with these threshold values to determine whether irrigation is necessary.

Additionally, the processing unit can be integrated with wireless communication modules such as Wi-Fi or GSM, enabling remote monitoring and control. This enhances system flexibility and allows farmers to access real-time data through mobile or web applications.



C. Output Unit

The output unit is responsible for executing control actions based on decisions made by the processing unit. It mainly includes a relay module and a water pump.

The relay acts as a switching device that controls the operation of the water pump. When activated by the microcontroller, the relay closes the circuit, allowing current to flow and turning the pump ON. When deactivated, it opens the circuit, turning the pump OFF.

This unit ensures precise water delivery to the crops, minimizing wastage and improving irrigation efficiency. Additional output components such as indicators (LEDs) or alarms can also be integrated for system status monitoring.

The output unit consists of a relay module and a water pump. The relay acts as an interface between the microcontroller and the pump, allowing the microcontroller to control the pump's operation. Additionally, the system can be integrated with wireless communication modules such as Wi-Fi or GSM to enable remote monitoring and control. This enhances the flexibility and usability of the system.

V. WORKING PRINCIPLE

The working principle of the proposed smart irrigation system is based on continuous sensing, real-time data processing, intelligent decision-making, and automated actuation to maintain optimal soil moisture conditions.

A. Data Acquisition:

The process begins with the soil moisture sensor, which is embedded in the soil near the root zone of the crops. The sensor continuously measures the moisture content present in the soil. Depending on the type of sensor used (resistive or capacitive), it detects moisture levels by measuring variations in electrical resistance or capacitance.

The sensor generates an analog voltage output proportional to the moisture level:

Low moisture → Low voltage (dry soil)

High moisture → High voltage (wet soil)

This analog signal is transmitted to the microcontroller for further processing.

B. Signal Processing and Calibration:

Upon receiving the sensor output, the microcontroller (such as Arduino or NodeMCU) performs Analog-to-Digital Conversion (ADC) to convert the analog signal into a digital value.

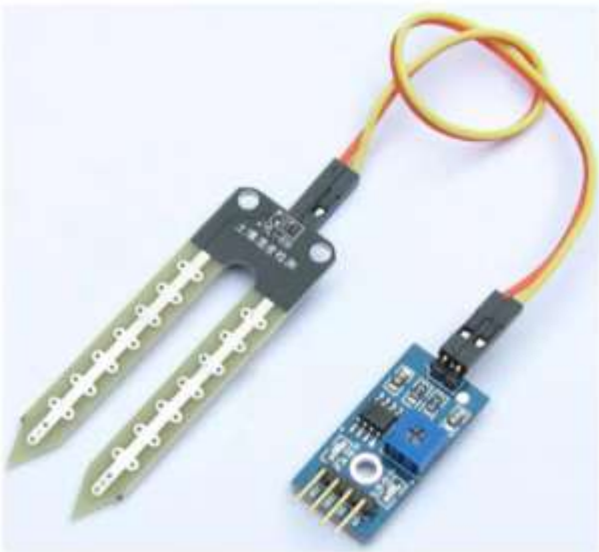
To improve accuracy, the system may include:

Calibration techniques to map raw sensor values to actual moisture percentages

Noise filtering methods (such as averaging multiple readings)

Error handling mechanisms to avoid false triggering due to sudden fluctuations

This ensures that the data used for decision-making is stable and reliable.



Soil Moisture Sensor

C. Decision-Making Mechanism:

The processed digital value is compared with predefined threshold values stored in the microcontroller program. These thresholds represent the optimal moisture range required for specific crops.

The decision logic operates as follows:

If Moisture Value < Lower Threshold

→ Soil is dry

→ Irrigation required

If Moisture Value ≥ Upper Threshold

→ Soil is sufficiently wet

→ Irrigation not required

In advanced implementations, hysteresis control is applied to avoid frequent ON/OFF switching of the pump, thereby increasing system stability and equipment lifespan.

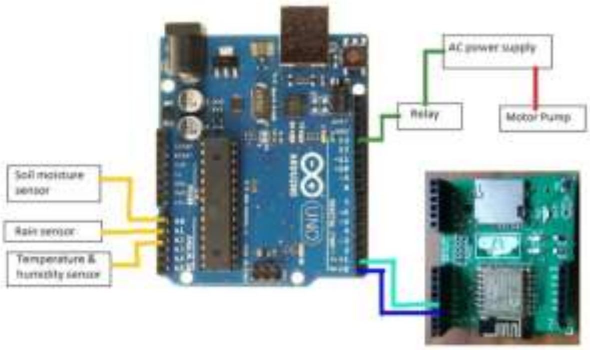
D. Control and Actuation:

Based on the decision, the microcontroller sends control signals to the relay module, which acts as an electrically operated switch.

When irrigation is needed, the relay is activated, completing the circuit and turning ON the water pump.

When sufficient moisture is reached, the relay is deactivated, breaking the circuit and turning OFF the pump.

This automated actuation ensures that water is supplied only when necessary, preventing over-irrigation and conserving water resources.



Smart Irrigation System using IoT

E. Continuous Monitoring Loop:

The entire process runs in a continuous loop, where the system repeatedly:

Reads sensor data

Processes and filters the signal

Compares with threshold values

Controls the pump accordingly

This loop enables real-time responsiveness to changing soil conditions, ensuring consistent maintenance of optimal moisture levels.

F. IoT Integration (Optional Enhancement):

In IoT-enabled versions, the system integrates with Wi-Fi or GSM modules to transmit data to cloud platforms. The working is extended as follows:

Sensor data is uploaded to a cloud server

Farmers can monitor moisture levels via mobile applications or web dashboards

Notifications or alerts are generated when moisture drops below critical levels

Remote control of the irrigation system is possible

This feature enhances usability, especially for large-scale agricultural fields.

G. Energy Efficiency Considerations:

To optimize energy usage, the system can incorporate:

Scheduled irrigation cycles

Sleep modes in microcontrollers

Integration with solar power systems
These features make the system sustainable and suitable for rural deployments.

H. Overall Operation Summary:

Thus, the smart irrigation system operates as an autonomous closed-loop control system, where sensing, processing, and actuation are tightly integrated. This eliminates manual intervention, improves water efficiency, and ensures better crop health and yield.

VI. ADVANTAGES

The proposed smart irrigation system offers several significant advantages over traditional irrigation methods:

A. Efficient Water Utilization:

The system supplies water only when the soil moisture level falls below a predefined threshold. This prevents over-irrigation and significantly reduces water wastage, making it highly suitable for regions facing water scarcity.

B. Automation and Reduced Human Effort:

Since the system operates automatically based on sensor data, it eliminates the need for constant manual monitoring. Farmers do not need to physically inspect soil conditions, thereby saving time and labor.

C. Improved Crop Yield and Quality:

Maintaining optimal soil moisture levels ensures that crops receive the required amount of water at the right time. This leads to healthier plant growth, increased productivity, and improved crop quality.

D. Energy Efficiency:

The automated ON/OFF control of the water pump reduces unnecessary energy consumption. The system can also be integrated with renewable energy sources such as solar panels for sustainable operation.

VII. APPLICATIONS

The smart irrigation system can be applied in various domain:

A. Agriculture Fields

It is widely used in farms to automate irrigation for crops such as rice, wheat, vegetables, and fruits, ensuring efficient water management.

B. Greenhouses:

In controlled environments like greenhouses, the system helps maintain precise moisture levels required for plant growth.

C. Gardens and Lawns:

The system can be implemented in residential gardens, parks, and lawns to automate watering and reduce manual effort.

D. Nurseries and Plantations:

Plant nurseries and plantations benefit from consistent watering, which is essential for young plants and saplings.

E. Smart Cities and Urban Landscaping:

Used in smart city projects for maintaining roadside plants, public parks, and landscapes efficiently.

VIII. FUTURE SCOPE

The proposed system can be further enhanced by integrating advanced technologies such as artificial intelligence and machine learning. These technologies can be used to predict irrigation requirements based on historical data and weather conditions.
The system can also be integrated with cloud computing platforms to store and analyze data. Mobile applications can be developed to allow farmers to monitor and control the system remotely.
Future developments may include the use of renewable energy sources such as solar power to make the system more sustainable.

IX. CONCLUSION

The smart irrigation system using IoT presents an efficient and sustainable solution for modern agricultural challenges. By integrating soil moisture sensors, microcontrollers, and automated control mechanisms, the system ensures optimal water usage based on real-time soil conditions.

The implementation of this system significantly reduces water wastage, minimizes human intervention, and enhances crop productivity. The incorporation of IoT technologies further enables remote monitoring and control, making it highly adaptable for large-scale agricultural applications.

Although certain limitations such as initial cost and maintenance exist, the long-term benefits in terms of water conservation, energy efficiency, and improved agricultural output outweigh these challenges.

In conclusion, the proposed system represents a step toward smart farming and precision agriculture, contributing to sustainable resource management and increased food production. Future enhancements involving artificial intelligence, cloud computing, and renewable energy integration can further improve the system's efficiency and reliability.

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