Design and Development of an IoT Based Smart Irrigation System in Agriculture Fields

Badipati Chinna Babu[1]; P. Venu[2]; V. Ravindra Kumar[3]; Y. Jhansi[4]; K. Geethanjali[5]

[1]Assistant Professor; [2]Student; [3]Student; [4]Student; [5]Student

[1;2;3;4;5]Department of Agricultural Engineering A.M Reddy Memorial College of Engineering and Technology, Narasaropet-522601

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Abstract: The project presents the design and implementation of a cost-effective IoT-based smart irrigation system aimed at enhancing agricultural efficiency through automation and remote monitoring. Utilizing an ESP32/NodeMCU microcontroller as the core unit, the system integrates a capacitive soil moisture sensor, DHT11 temperature and humidity sensor, relay module, and water pump or solenoid valve to automate irrigation based on real-time soil moisture readings. An LCD display and GSM module provide on-site monitoring and SMS alerts to keep farmers informed of environmental conditions and system status. The hardware and software components were carefully chosen to maintain low cost while ensuring reliable performance. Field testing under various environmental conditions demonstrated consistent sensor accuracy, effective pump control, and significant water conservation. The system, developed at an approximate cost of ₹2,970, proved suitable for small to medium-scale farms, especially in rural areas. Its successful operation confirms the potential of IoT in promoting sustainable farming, optimizing resource utilization, and improving overall crop management, establishing a scalable foundation for future smart agriculture innovations.

Keywords: *Smart Irrigation, IoT, Automation, Soil Moisture Sensors, Smart Farming, Real-Time Data Analysis.*

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I. INTRODUCTION

A Smart Irrigation System based on the Internet of Things (IoT) represents a modern, data-driven approach to agricultural water management, addressing inefficiencies associated with traditional irrigation methods. Conventional systems often rely on manual intervention or fixed schedules, leading to overwatering or underwatering and unnecessary resource waste. In contrast, IoT-based irrigation leverages real-time data from soil moisture, temperature, and humidity sensors to make automated, precise decisions about when and how much water to deliver. Core components such as ESP32/NodeMCU microcontrollers, soil moisture sensors, DHT11 temperature/humidity sensors, relay modules, and water pumps work in harmony to create an efficient, responsive irrigation system. Additionally, communication modules like GSM enable remote monitoring and control, making the system practical for both small-scale gardens and large agricultural fields.

This smart irrigation system conserves water by activating irrigation only when needed, based on sensor data and environmental conditions. With the ability to monitor and manage operations remotely via mobile apps or web dashboards, users gain enhanced control and flexibility. The system not only reduces manual labor and operational costs but also supports sustainable farming by minimizing water waste and promoting healthy crop growth. Looking ahead, integrating technologies like AI, solar energy, and machine learning could further enhance the intelligence, energy efficiency, and adaptability of such systems. Overall, IoT-based smart irrigation systems offer a transformative solution for efficient, scalable, and environmentally responsible agriculture.

➢ *Objectives of Current Study*

- To design and develop an intelligent irrigation system for efficient agricultural management.
- To implement an autonomous system capable of making irrigation decisions based on real-time climatic conditions.
- To optimize crop yield through precise and timely water management.
- To enhance water use efficiency by minimizing wastage and maximizing effectiveness.

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II. REVIEW OF LITERATURE

The literature on IoT-based smart irrigation systems reflects the growing importance of integrating technology into agriculture to enhance water efficiency and crop yield. Ahmed et al. (2019) and Patel et al. (2020) emphasized the significance of real-time monitoring of soil and environmental parameters using sensor networks, which facilitate automated decision-making through cloud connectivity. Studies by Singh et al. (2020) and Reddy et al. (2020) highlighted the benefits of automation in managing water flow and scheduling irrigation based on soil moisture and weather data, while also noting challenges such as sensor calibration, rural connectivity, and system scalability. Das et al. (2021) and Verma et al. (2021) provided comprehensive insights into sensor-based systems, stressing the role of data analytics, microcontroller selection, and software integration in achieving efficient, low-cost solutions for small to medium farms.

Further contributions by Mishra et al. (2021), Chen et al. (2021), and Yadav et al. (2021) explored advanced features such as mobile applications for remote monitoring, cloud-based data management, and the integration of GSM and Wi-Fi for real-time communication. Ali et al. (2021) and Iqbal et al. (2022) focused on the reliability and structure of wireless sensor networks and emerging trends like edge computing and machine learning for forecasting irrigation needs. More recent reviews by Sharma et al. (2022), Kapoor et al. (2022), Bose et al. (2022), and Gupta et al. (2022) examined sustainable water management strategies and the role of AI in predictive irrigation control. These works collectively demonstrate the potential of IoT in transforming traditional irrigation methods into intelligent, data-driven systems that enhance sustainability and productivity in agriculture.

III. METARIALS AND METHODS

- *Soil Moisture Sensor*

A soil moisture sensor measures the water content in the soil to help optimize irrigation. It works by detecting changes in electrical resistance or capacitance based on moisture levels. These sensors are energy-efficient, durable, and easily integrated into smart irrigation systems for automated watering. Key features include adjustable sensitivity, weather resistance, and accurate performance for reducing water waste.

- *Arduino UNO*

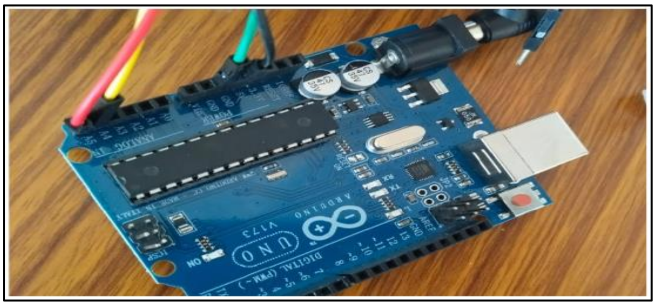

Fig 1 Arduino UNO

The Arduino Uno is a popular open-source microcontroller board based on the ATmega328P, widely used for prototyping in IoT, automation, and embedded systems. Programmed via the Arduino IDE using C/C++, it supports communication protocols like UART, SPI, and I2C for easy hardware integration. Its affordability, simplicity, and versatility make it ideal for projects such as smart irrigation, home automation, robotics, and industrial applications.

- *LCD Display*

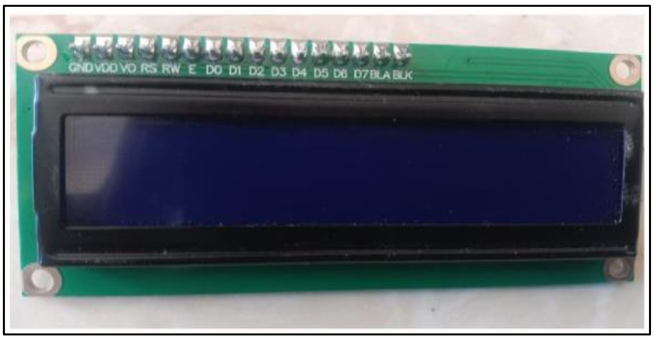

Fig 2 16x2 LCD (Liquid Crystal Display).

In smart irrigation systems, LCD displays play a key role in providing real-time monitoring of sensor data such as soil moisture, water flow, weather conditions, and system status. Connected to a microcontroller, the LCD offers clear visual feedback, enabling users to track and adjust irrigation settings as needed. With features like low power consumption, outdoor visibility, and easy integration, LCDs help farmers make informed decisions, ensuring efficient water usage and healthier crop management.

- *Relay*

Fig 3 Relay

A relay is an electrically operated switch used in smart irrigation systems to control high-power devices using low-power signals. It provides isolation between control and power circuits, ensuring safe operation. When current flows through its coil, a magnetic field moves the armature to open or close the circuit. Relays are known for their durability, fast response, and ability to handle high-voltage or high-current loads.

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➢ *Jumper Wires*

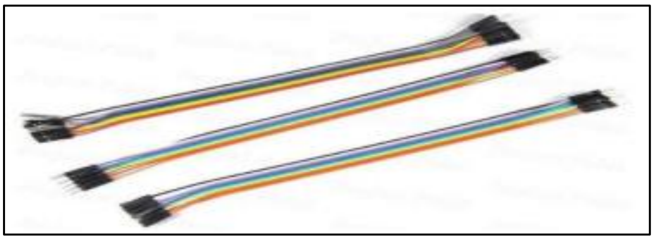

Fig 4 Jumper Wires

Jumper wires are flexible electrical conductors commonly used in electronics and IoT projects to establish temporary or permanent connections between components on a breadboard or circuit board. In this project, male-to-female jumper wires are used, where one end features a male pin and the other end a female connector, allowing easy interfacing between modules and microcontrollers.

➢ *Power Adaptor*

A power adapter is an essential component that supplies the required electrical power to devices like sensors, microcontrollers, and communication modules. It converts AC (alternating current) from the mains into DC (direct current), ensuring safe and reliable operation of the entire system.

Fig 5 Power Adaptor

➢ *D.C. Motor:*

A power adapter is a vital component in electronic and IoT systems, providing the necessary power for operation. It converts AC (alternating current) from a wall outlet into DC (direct current), which is suitable for powering devices like sensors, microcontrollers, and communication modules. This conversion ensures that all components receive a stable and safe voltage. Without a proper power supply, the system may malfunction or become damaged. Therefore, a reliable power adapter is crucial for the efficient and uninterrupted functioning of the entire setup.

Fig 6 DC Motor

➢ *Arduino UNO Pinout Description*

The Arduino Nano is a compact and breadboard-friendly microcontroller board with 14 digital I/O pins and 6 analog input pins. Each pin can serve multiple functions and can be configured as input or output based on the application. Functions like pinMode(), digitalWrite(), and analogRead() control pin behavior, with analog pins offering 10-bit resolution from 0 to 5V. Operating at 5V with a 16 MHz crystal oscillator, it ensures reliable real-time processing. Although it lacks a DC power jack, it supports Mini USB for programming and communication.

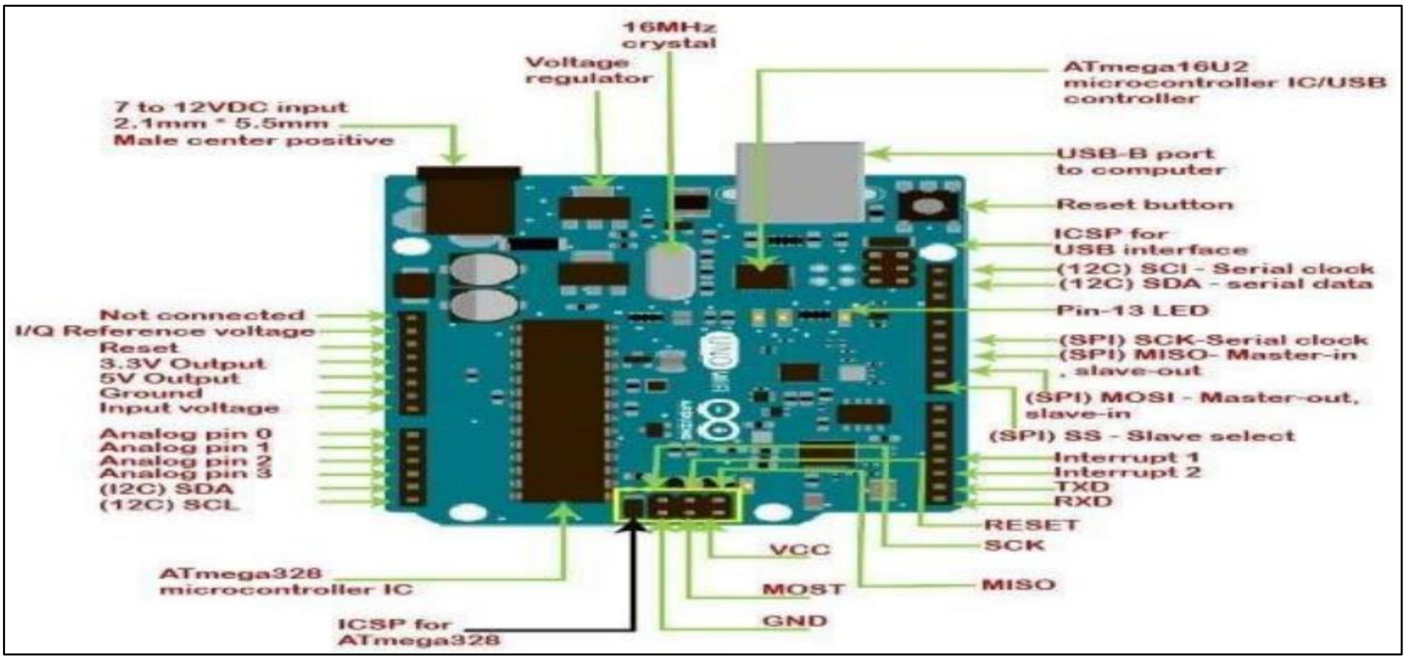

Fig 7 Arduino UNO Pinout Description

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➢ *Emitting Pipes*

Fig 8 Emitting Pipes

Emitting pipes in smart irrigation systems deliver water directly to plant roots through controlled openings, ensuring precise irrigation based on soil moisture data from IoT sensors. These pipes promote water conservation, reduce wastage, and enable efficient water flow with low maintenance. Integrated IoT allows for remote monitoring and automated irrigation, supporting sustainable farming practices.

➢ *Nozzles*

In smart irrigation systems, nozzles regulate and distribute water efficiently, spraying in patterns like mist, cone, or stream based on crop requirements. IoT sensors track factors like soil moisture, temperature, and weather to adjust the water output from the nozzles, minimizing water wastage. This ensures optimal irrigation and promotes healthy crop growth. Features include adjustable spray patterns, low water consumption, and seamless IoT integration for remote control. The nozzles help maintain the right soil moisture and support sustainable farming. The nozzle diameter is 0.5 mm.

Fig 9 Nozzles

IV. METHODOLOGY

➢ *System Design and Implementation*

The smart irrigation system automates water supply using real-time soil moisture data to conserve water and boost crop productivity. It consists of input sensors (soil moisture and optional temperature-humidity), an Arduino UNO as the processor, and output devices like a relay-controlled water pump, 16x2 LCD, and GSM module for SMS alerts. When dry soil is detected, the Arduino activates the pump and sends system updates via SMS while displaying the status on the LCD. All components are mounted on a breadboard or PCB with a regulated power supply, and the system is programmed using Arduino IDE in C/C++ for sensor reading, pump control, messaging, and display.

➢ *Testing, Validation, and Observations*

The system was successfully tested in both lab and field settings. It accurately monitored soil conditions, triggered the pump when needed, and sent SMS alerts using GSM. The LCD provided real-time updates, and all components functioned reliably. Field deployment confirmed its effectiveness under real conditions, proving its suitability for automated and sustainable irrigation.

V. RESULTS

Table 1 Test Results of IoT-Based Smart Irrigation System under Varying Soil and Environmental Conditions

Test No.	Date & Time	Soil Moisture (ADC)	Soil Condition	Water Available	Pump Status	Temp (°C)	Humidity (%)	LCD Display	SMS Sent
1	6/2/25 & 1:03	780	Dry	Yes	ON	35	60	Dry soil: ON	PUMP: OFF
2	10/2/25 & 1:04	785	Dry	No	OFF	32	55	Dry soil: ON	PUMP: OFF
3	15/2/25 & 10:01	650	Moist	Yes	OFF	28	50	Moist soil: OFF	PUMP: OFF
4	23/2/25 & 9:02	280	Soggy	Yes	OFF	27	65	Soggy soil: OFF	PUMP: OFF
5	26/2/25 & 2:04	720	Dry	Yes	ON	36	58	Dry soil: ON	PUMP: ON
6	1/3/25 & 10:03	690	Moist	Yes	OFF	30	52	Moist soil: OFF	PUMP: OFF

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VI. DISCUSSION

The results from the field and laboratory tests demonstrate the effectiveness and reliability of the IoT-based smart irrigation system in various soil and environmental conditions. The system accurately detected changes in soil moisture through ADC values, with the pump activating automatically when the soil was dry and water was available, as seen in Test Nos. 1 and 5. It correctly turned off the pump when soil moisture reached moist or soggy levels, conserving water and preventing over-irrigation (Tests 3, 4, and 6). Temperature and humidity variations were also recorded, indicating the system's ability to function consistently across different climatic conditions. Moreover, the LCD display provided clear real-time information, and SMS alerts were successfully sent, keeping the user informed about soil status and pump activity. These observations confirm the system's potential for practical implementation in agricultural fields, enabling automated irrigation with minimal human intervention and enhanced water management.

VII. CONCLUSION

The IoT-based smart irrigation system proved to be an effective solution for automated and efficient water management. It accurately detected soil moisture levels, responded appropriately by controlling the water pump, and provided real-time updates via LCD and GSM alerts. Both lab and field tests confirmed the system's reliability, reducing manual intervention and water wastage. Overall, it offers a practical and sustainable approach for modern agriculture, especially in regions facing water scarcity.

FUTURE SCOPE

The smart irrigation system can be further enhanced by integrating artificial intelligence (AI) and machine learning (ML) algorithms to predict irrigation needs based on weather forecasts and historical data. Incorporating solar power will make the system more sustainable and energy-efficient, especially in remote areas. Future versions could also support IoT cloud platforms for advanced data analytics and remote multi-farm management through mobile or web dashboards. Additionally, using wireless communication technologies like LoRa or NB-IoT can improve connectivity in rural and large-scale agricultural fields, ensuring broader adoption and scalability.

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