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IOT POWERED SMART IRRIGATION SYSTEM: BALANCING PERFORMANCE AND ENERGY EFFICIENCY

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***Abstract*—** Countries are working towards making agriculture more sustainable by integrating various technologies to improve its operations. Implementing improvements in irrigation systems is crucial for water-use efficiency and contributes to Goal 6 and Goal 6.4 of the United Nations Sustainable Development Goals (SDGs). This research paper aims to highlight the contribution of smart irrigation using the Internet of Things (IoT) and sensing systems to the Sustainable Development Goals. This study is based on a qualitative design and focuses on secondary data collection methods. Automated irrigation systems are essential for water conservation, and improvements can play a significant role in reducing water use. Agricultural and farming technologies are also being integrated with IoT and automation to make the entire process more effective and efficient. Sensor systems have helped farmers better understand their crops, reduce environmental impacts, and conserve resources. These advanced systems enable efficient water management, as well as effective soil and weather monitoring. Irrigation systems are identified as positive contributors to optimized irrigation systems, which can lead to increased use of ongoing research and development focused on enhancing sustainable operations and reducing costs. Finally, the challenges and benefits of implementing sensor-based irrigation systems are discussed. This review will help researchers and farmers better understand irrigation technologies and provide adequate perspectives for irrigation activities

***Keywords*—**Irrigation, Sustainable Development goals, Smart Irrigation, Agriculture

1. Introduction

Water is one of the most vital resources in agriculture, yet it is often the most mismanaged. In many parts of the world, farmers still rely on fixed schedules or manual assessments to irrigate their crops, leading to overwatering, under-watering, and ultimately, wasted resources and reduced yields. As climate patterns become more unpredictable and freshwater availability continues to decline, the agricultural sector faces a critical challenge: how to grow more food with less water, less energy, and greater precision.

In this context, the integration of Internet of Things (IoT) technologies into irrigation systems has emerged as a game-changer. By connecting soil sensors, weather data, and irrigation infrastructure to smart algorithms and cloud platforms, IoT-powered smart irrigation systems leverage a network of interconnected sensors, actuators, and communication technologies to monitor environmental parameters such as soil moisture, temperature, and humidity in real-time. This data is then used to make informed decisions about when, where, and how much to irrigate, optimizing both crop yield and resource usage. This shift from manual control to intelligent automation has the potential to not only improve crop productivity but also reduce the strain on natural resources. However, while these systems offer significant performance improvements in irrigation management, they also introduce new challenges related to energy consumption, system scalability, and operational sustainability.

IoT technologies are allowing farmers to move from guesswork to precision. By placing moisture sensors in the soil, tracking weather data, and automating water delivery systems, farmers can give crops exactly what they need—no more, no less. Instead of sticking to a rigid schedule, irrigation decisions can now be made based on real-time information.

These systems aren't just smarter—they're also more efficient. Many use solar power, low-energy communication technologies like LoRa or NB-IoT, and data processing tools that only activate when needed. This helps reduce both power consumption and costs. And because they can be monitored remotely using a phone or a laptop, they dramatically cut down on labor, making it easier to manage even large or scattered farms.For farmers dealing with climate uncertainty, smart systems offer the ability to react more quickly. If a sudden drop in temperature or a dry spell is coming, sensors and AI-based tools can adjust the irrigation automatically, helping to protect crops and save resources.

2. LITERATURE REVIEW

In [1], an IoT based smart irrigation system based on renewable energy was introduced to reduce agriculture. In [2], another IoT based smart irrigation system using soil moisture sensor and computing module to monitor soil moisture content and automate irrigation was developed, thereby reducing human intervention and conserving water by providing water based on plant requirements. In [3], an overview of smart irrigation systems using IoT was designed to highlight the contribution of smart irrigation systems using IoT and sensing systems with respect to Sustainable Development Goals (SDGs). In [4], an automated irrigation system using IoT devices was developed to design a low-cost automated irrigation system that helps underprivileged farmers save time and money by automating irrigation and providing manual control through an Android app. In [5], an Intelligent IoT-Multi-Agent Precision Irrigation Approach for Improving Water Use Efficiency was proposed in Irrigation Systems at Farm and District Level. It aims to design and implement an intelligent IoT-Multi-Agent Precision Irrigation approach aimed at improving water use efficiency at farm and district level. In [6], a Smart Energy model for Smart Irrigation to investigate the possibility of reducing irrigation costs using technologies used in smart energy systems, particularly by proposing a simulation approach based on renewable energy sources (RES) installations. In [7] a model to propose a novel combination of customized intelligent smart irrigation systems to improve energy management performance, address problems such as data transmission failure and network lifetime reduction in IoT-based agriculture. In [8], an IoT-Based Low-Cost and Intelligent Module for Smart Irrigation System was developed for smart irrigation that provides capabilities such as user interaction, one-time setup for irrigation scheduling, neural network-based decision making, and remote data monitoring. In [9], an IoT-enabled smart irrigation technology adapting to weather conditions in precision agriculture systems optimizes irrigation use through precision water valve management, using neural network-based forecasting of soil water requirements one hour in advance. In [10], an IoT-based smart irrigation management system using machine learning and open-source technologies was presented. An open-source technology-based smart system that forecasts field irrigation requirements, with the aim of optimal use of water-resources in precision agriculture was used. In [11], a smart system for smart energy consumption and smart irrigation was proposed for efficient plant irrigation that saves water and supports smart energy consumption, while addressing the limitations of existing sensor-based systems in tunnel agriculture.

3. PROPOSED SYSTEM DESIGN

The proposed system uses several input and output devices, including a solar panel connected to a power source, temperature and humidity sensors, an input device, and a humidity and motor pump, an output device. The photovoltaic system is integrated into the solar panel system, providing renewable energy from solar power to power the connected water pump. The ESP8266 is connected to three sensors—temperature, humidity, and soil moisture—and the solar panels, which power the water pump. The ESP8266's Wi-Fi connectivity allows remote monitoring of weather variables such as temperature, humidity, and soil moisture. Farmers can view the overall weather conditions of their land area using the internet from a remote location. They can monitor soil moisture conditions using a cloud application on their Android phone and determine whether the cultivated area needs watering. The intended blocks are described, and the proposed system is illustrated in Figure 1 below.

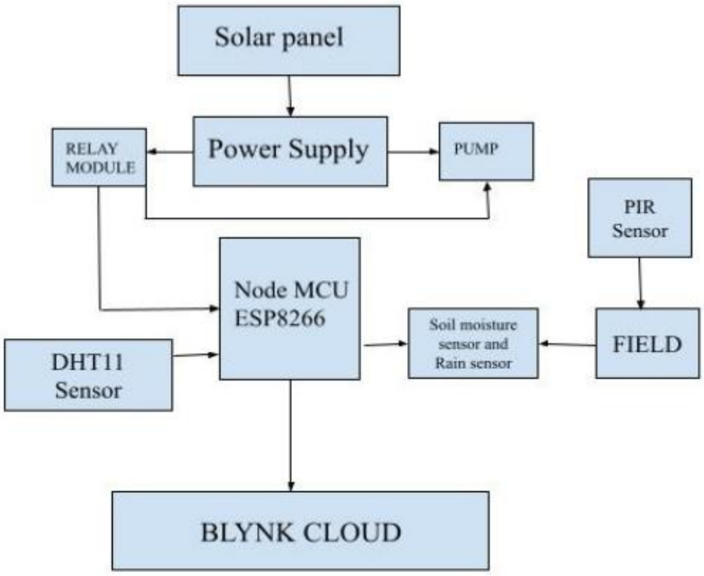


Fig: IoT Based Smart Irrigation System Block Diagram

A: Relay:

A relay is an electrical device used to mechanically operate a switch. It is used to control multiple circuits from a single output. The main function of amplifiers is to transfer signals [16]. Relays are used as switches.

B. Solar Panel

A solar panel is a device that converts light energy from the sun into electrical energy for the operation of any system [8]. A solar panel is made of photovoltaic (PV) cells [16]. The cells in a solar panel are energized by sunlight. The cells are energized by the sun's rays, generating heat energy, and terminals on the back of the supporting structure convert the generated heat energy into electrical energy, which is then stored in an external battery via wires.

C. ESP8266 WiFi Module

The ESP8266EX Wi-Fi module is controlled using the TCP/IP protocol, allowing it to access any type of wireless connectivity network. It allows various sensors to be connected to the Wi-Fi module via GPIO pins. It processes sensor data in minimal time. The Wi-Fi module microchip is connected to a microcontroller where the data is processed and acts as a carrier for transferring data from sensors and other connected systems to a server built using Blink Cloud.

D. Sensors

IIn the proposed system, sensors play a crucial role in detecting the moisture content in the field, measuring the humidity level in the atmosphere, measuring the amount of water in the field, and detecting the remaining voltage in the external battery [16]. The list of sensors used in our system is as follows:

Moisture sensor: The sensor will measure the moisture content of the soil around it. The detection range of the moisture sensor is approximately 1 square foot. If the moisture content is low, the module transmits data through the output pins and displays the output through the microcontroller.

Temperature sensor: The temperature and humidity sensors sense the temperature and water vapor in the field [16] and range from 15°C to 40°C.

PIR Sensor: Detects movement , For example a cow is coming to gazing at the crop in this case a LED or Alarm rings.

Rain Sensor: Detects Rainfall if there is rain then the pump remains turned off.

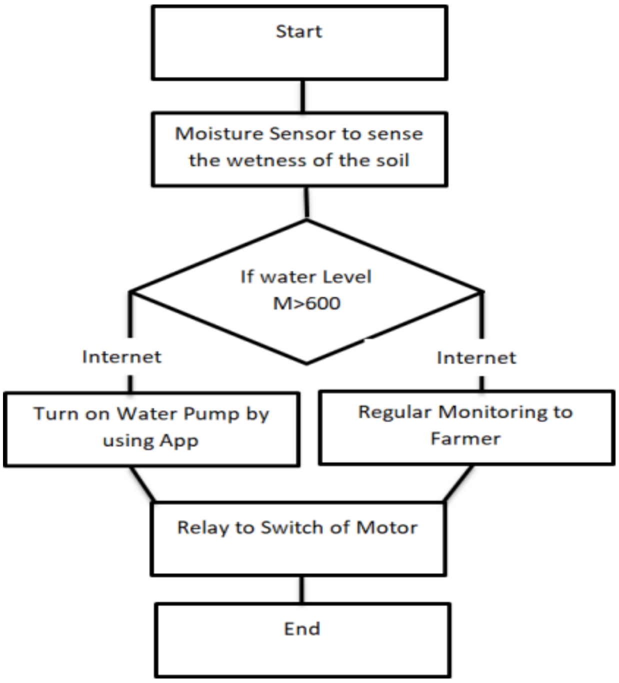
Agriculture has always been highly dependent on unpredictable natural forces. Today, this unpredictability is amplified by shrinking freshwater supplies, increasing energy costs, and a rapidly changing climate. Farmers, whether operating large commercial farms in developed regions or small fields in rural areas, face rising pressure to maximize output with limited resources. Traditional irrigation systems often run on pre-set schedules, regardless of actual soil conditions. This leads to water wastage and crop stress, worsening global freshwater scarcity, especially when agriculture already accounts for the majority of freshwater use. Rising fuel and electricity costs add further strain, increasing the environmental footprint and making irrigation even less sustainable.

Additionally, workforce challenges persist. With fewer young people entering farming and older generations working with limited labor, manual irrigation becomes increasingly difficult. Errors such as delayed or excessive watering directly affect productivity. Moreover, climate unpredictability—erratic rainfall, extended droughts, and heatwaves—makes reliance on traditional methods inadequate. IoT technologies are helping agriculture transition from guesswork to precision farming. Soil moisture sensors, weather data integration, and automated irrigation control allow crops to receive exactly the amount of water required—no more, no less. Unlike rigid schedules, real-time monitoring enables adaptive decision-making.Many IoT-based systems are also designed to be energy efficient, using solar-powered sensors, low-energy communication standards such as LoRa and NB-IoT, and on-demand data transmission to reduce energy consumption. Remote monitoring via smartphones or computers further reduces labor requirements, making management easier across both small and large farms.These systems also enable farmers to respond swiftly to environmental changes. For instance, during sudden droughts or temperature shifts, automated algorithms can adjust irrigation instantly, safeguarding crops and reducing losses.However, challenges remain. High installation costs limit adoption by small-scale farmers. In remote regions, poor network infrastructure creates barriers. Additionally, the need for training and digital literacy among farmers can slow the adoption process.To overcome these issues, governments, NGOs, and private companies are working together to subsidize technologies, simplify IoT systems, and even introduce subscription-based irrigation services to make smart farming more accessible.

4. System Implementation

- The IoT-based smart irrigation system based on solar energy is shown in Figure-2 and it uses various hardware including DHT11 sensor, Wi-Fi module, solar panel, soil moisture sensor and relay module to sense and monitor soil moisture, temperature and humidity parameters in the irrigation area.The soil moisture sensor checks the soil condition.
- If the moisture level is below the threshold, NodeMCU activates the relay to turn ON the water pump.
- The pump waters the plants until the moisture level is sufficient.
- If rain is detected, the system prevents watering to save water.
- Environmental data (temperature, humidity) can be monitored and analyzed for better irrigation control.
- PIR Sensor is also used to detect motion

Fig 2: Implementation Scenario of Smart Irrigation System



Flowchart: IoT based smart irrigation System

The IoT-based smart irrigation system starts with the moisture sensor, which measures the wetness of the soil. If the soil moisture level is found to be greater than 600, the system, through the internet, turns on the water pump using the mobile app and also provides regular monitoring updates to the farmer. Once irrigation is sufficient, the relay switches off the motor, and the process ends.

5. RESULT ANALYSIS

The sensor's input values are humidity, temperature, and soil moisture. "Hot" and "Cold" are the two temperature functions used. Three functions—"High" and "Low"—are used for the soil moisture and humidity sensors. The watering motor operates through fuzzy logic using "if" and "else" conditions. When the application displays a message indicating that the temperature is high and the humidity is low, the crops are watered; when it returns "False," the crop field is not watered. This concept is illustrated in Table 1 and Figure 3 above.

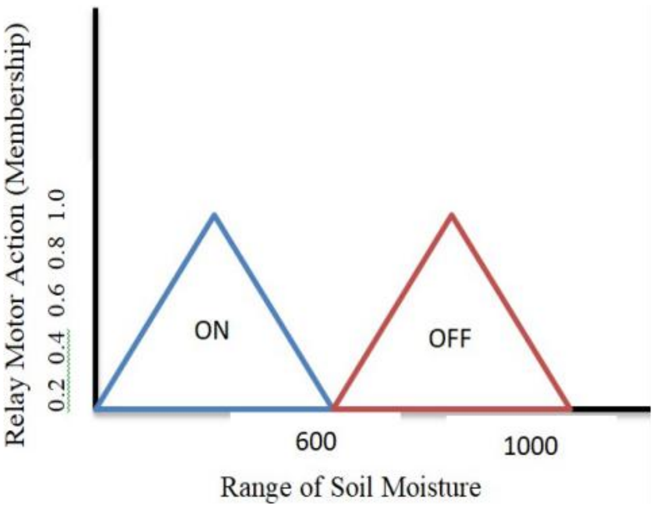


FIG 3: FUZZY LOGIC CONCEPT FROM SOIL MOISTURE AND RELAY MOTOR ACTION

Temperature and humidity are separate entities, but they are related. The relationship between humidity and temperature is simply that they are inversely proportional. If the temperature increases, the relative humidity will decrease, making the air drier, while if the temperature decreases, the air will become moister, meaning the relative humidity will increase.

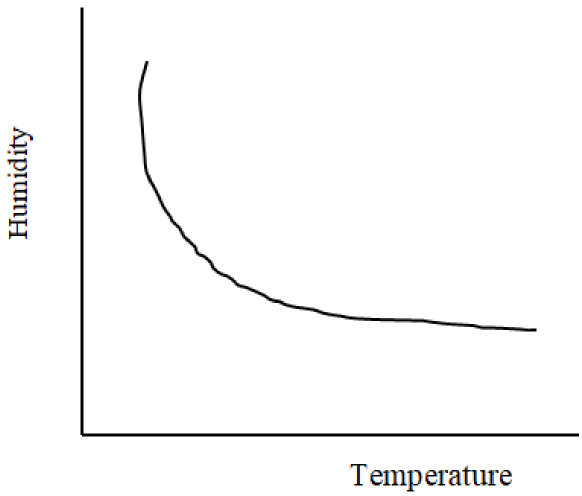


Fig: Inverse relationship between temperature and Humidity

The water pump control in an IoT-based smart irrigation system depends on three parameters: moisture level, temperature, and humidity, as measured by respective sensors.When the moisture sensor indicates a water quantity level in the range of 500–600 units, the temperature sensor records 25–28°C, and the humidity sensor shows a value between 40–60 RH (gm/kg), the system decides that the soil has adequate moisture and environmental conditions are favorable. Therefore, the relay motor remains OFF, and no irrigation is required.

On the other hand, when the moisture sensor detects a water quantity level in the range of 1000–1200 units, the temperature sensor shows a higher value of 30–35°C, and the humidity sensor indicates a low reading of less than 30 RH (gm/kg), the system identifies that the soil and air are too dry and water supply is essential. In this case, the relay motor is switched ON to start irrigation. Thus, by continuously monitoring soil moisture, temperature, and humidity, the system can intelligently control the water pump using Blynk data, ensuring efficient and automated irrigation.

6. CONCLUSION AND FUTURE SCOPES

A successful automated smart irrigation system has been developed that analyzes soil conditions and determines whether to irrigate a field using fuzzy logic and a variety of sensors, including soil moisture and DHT sensors. Furthermore, we were able to install this system without electricity because we solar-powered all sensors using an ESP8266 module. The system's design aims to address the problems of traditional irrigation systems, which result in significant resource wastage. By implementing an automated function that allows users to remotely monitor soil conditions, water pumping requirements, and other factors, unnecessary manpower is eliminated. The proposed approach is cost-effective and easy to install in large enough spaces for crop cultivation, such as gardens and rooftops. As we increasingly rely on renewable energy sources, using solar energy as the primary energy source was an added advantage. The integration of a Wi-Fi module improved the design's adaptability by allowing for greater flexibility and the addition of more sensors with only a little additional programming. This concept could be scaled to suit actual farm sizes in the future, supporting operations without the human intervention and manpower required for irrigation, and could also be used to reduce the cost of equipment used to install and operate irrigation systems.

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