A Holistic IoT-Based Approach for Smart Farming for Irrigation Optimization and Leaf Disease Detection

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Abstract. The "A Holistic IoT-Based Approach for Smart Farming for Irrigation Optimization and Leaf Disease Detection" is an advanced solution aimed at optimizing water usage and promoting healthy crop growth through automated monitoring and control. The system integrates a soil moisture sensor to detect dryness and activates the water inlet pump, while a pH sensor ensures water quality by controlling the outlet pump when pH levels are unsuitable. It also features an LDR for measuring light intensity, an MQ135 sensor for monitoring air quality, and a DHT11 sensor for tracking temperature and humidity. An Arduino Mega microcontroller processes the sensor data, which is displayed on an LCD. A USB camera is attached to take a photo of the leaf disease. Problem Statement: This project detects the plant diseases and it also recommends the pesticides for plant disease. It helps farmers act quickly to safeguard crops. Live data is sent to the Thing Speak servers via a NodeMCU, and there is a Bluetooth interface to a mobile app. GSM alerts for abnormal condition ensure dual-pump use and complete monitoring to save energy, lower labor and promote concept of sustainable farming.

Keywords: Nodemcu, Alert, PH Sensor, LCD, IOT.

1 Introduction

Water-efficient management is an essential aspect in today's agriculture, especially in water-stressed areas [1]. Traditional way of watering the field leads to water wastage and uneven crop growth [2]. In dealing with the challenges, The Smart Irrigation System employs modern technology to provide an efficient, automated solution for the irrigation process. A combination of sensors and microcontrollers in the system makes water applied efficiently, thus improving crop yield and reducing the wastes of resources.

This novel system includes soil moisture, pH, light intensity, air quality, and environment temperature and humidity sensors, which allow for real-time measurements of key parameters [3]. The system is composed of these sensors and an Arduino Mega microcontroller that is responsible for processing sensor's data and actuating two pumps for water supply and quality control. This application recognizes plant diseases and recommends suitable pesticides. It can inform farmers how to act to safeguard crops. It has other functions, such as a USB camera for leaf disease detection and NodeMCU for uploading data to Thing Speak to the cloud. Transmission with the Bluetooth module and GSM alarms also guarantees an intelligent monitoring and management, which makes the Smart Irrigation System a complete product for sustainable farming.

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The “Smart Irrigation System” is intended to meet the increasing need of environmentally-friendly and resource-saving agriculture. By incorporating cutting edge sensors, it tracks environmental and soil conditions in real time, so farmers can decide based on proprietary data which make their crops healthier and yield better. This degree of automation greatly saves water, is environmentally friendly, and responsive to the different eco-conditions.

2 Related Works

Several researchers have explored the role of IoT-based technologies in enhancing agricultural efficiency and water management. Vadlamudi et al. [1] demonstrated a LabVIEW-based system for monitoring and controlling soil relative humidity, enabling automation of irrigation with minimal human intervention. Their approach highlighted the benefits of continuous soil moisture tracking but was limited in terms of large-scale deployment.

At a broader level, Al-Fuqaha et al. [2] provided a comprehensive survey of Internet of Things (IoT) technologies, protocols, and applications, emphasizing agriculture as one of the key domains where IoT can optimize resource usage and improve decision-making. Building on this foundation, Tan et al. [3] proposed an ARM and IoT-based irrigation system for soil moisture monitoring, showing improvements in efficiency compared to conventional irrigation methods.

Recent advancements focus on intelligent decision-making and water optimization. R. et al. [4] introduced an IoT-driven smart irrigation system designed to optimize water usage in agriculture, achieving measurable reductions in water wastage while maintaining crop yield. Similarly, Karthikamani and Rajaguru [5] developed a Raspberry Pi–based system that combined multiple sensors for real-time data acquisition, illustrating the feasibility of low-cost, scalable solutions for farmers.

The integration of machine learning with IoT has also gained attention. Kanade and Prasad [6] implemented an Arduino-based system that applied machine learning algorithms for smart irrigation, enabling predictive control of water distribution based on crop needs. Complementing such approaches, Obaideen et al. [7] reviewed the state of smart irrigation systems and emphasized their potential to support sustainable agriculture by leveraging IoT platforms for real-time monitoring and adaptive control.

Earlier contributions, such as the work of Suba et al. [8], explored wireless sensor networks for smart irrigation. Their study demonstrated how distributed sensing could improve irrigation efficiency, laying the groundwork for current IoT-enabled systems.

3 Proposed Method

The proposed system comprises a suite of sensors such as Heart beat sensor, Dallas Temperature Sensor (DS18B20), GSR sensor, MEMS sensor, Pressure sensor, and NodeMCU interfaced through Arduino MEGA to form a dynamic monitoring and alert system. By the combined operation of these parts, the sensors data are processed by NodeMCU and Arduino MEGA. For example, MEMS accelerometers monitor human motion by monitoring sudden hits or falls, thus providing a view of the worker's activity level and any potential accidents. This project recognizes plant diseases and recommends suitable pesticide for the same. It alerts farmers in time to take measures to protect their crops. In addition, MEMS inclinometers determine the tilt or inclination of the worker which helps in accident prevention on rooftops. Furthermore, the system is designed to use a buzzer for rapid alerts using the monitored data. Fig. 1 shows the Block Diagram

Block Diagram:

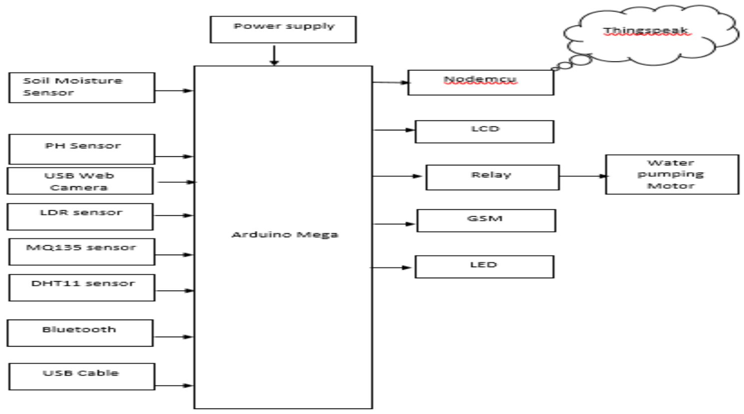

Fig. 1. Block Diagram.

4 Methodology

Hardware components for this project includes:

4.1 Arduino Mega:

The Smart Irrigation System is built around the Arduino Mega, which acts as the principle microcontroller used for the processing of the input from the different sensors and controlling the functioning of the overall system (fig 2).

Fig. 2. Arduino Mega.

Furthermore, the Arduino Mega can communicate with peripheral devices such as the LCD display, USB camera and GSM module, providing real-time feedback and monitoring. The centralized control and data management offer by the Arduino Mega optimizes its performance, making it a crucial part of the project for automation and efficient management of irrigation.

4.2 Soil Moisture Sensor:

In the Smart Irrigation System, the soil moisture sensor is essential for determining effective water usage by automatically monitoring soil moisture levels. This automatic monitoring can minimize manual control, and save water in only when irrigation is required (fig 3).

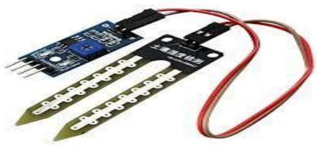

Fig. 3. Soil Moisture Sensor.

The SM sensors sends real-time data to the Arduino Mega microcontroller, which is the brain of the operation and processes the information to act to provide water to the plant in an eco-friendly and effective manner while also maintaining water in farming.

4.3 PH Sensor:

The pH sensor installed in the Smart Irrigation System is an important device for measuring the quality of water for irrigation. By adding the pH sensor, the product provides a complete solution for water quality and good irrigation (fig 4).

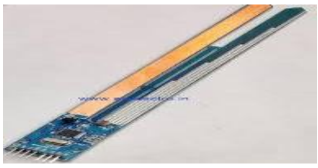

Fig. 4. PH Sensor.

4.4 USB Web Camera:

The Smart Irrigation System utilizes a USB web camera as an important device to monitor plant health through the imagery of crops. This early warning helps to keep crops healthy and protect against devastating crop losses from undetected disease (fig 5).

Fig. 5. USB Web Camera.

The USB web camera also contributes to it being a real-time monitoring system in combination with other sensors because visual data provides more information than other sensors. This project is used to detect plant disease and recommends pesticides for detection of plant disease. It helps farmers respond to threats to crops. The inclusion of a USB web camera therefore provides an important depth of vision to the automatic irrigation system and aids in more intelligent decision-making.

4.5 LDR Sensor:

As the light is one of the major factors for the automatism is the LDR (Light Dependent Resistor) sensor of Smart Irrigation System is used to sense the light of the environment. The addition of LDR makes the system more adaptive for various weather and can keep the growth status best by considering the sunlight exposure (fig 6).

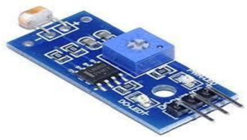

Fig. 6. LDR Sensor

We added the LDR sensor to the irrigation system, and record the history of all the environment factors that may condition agriculture. This is a making this app even more accurate, and environmentally and resource friendly form of farming.

4.6 MQ135 Sensor:

The Smart Irrigation System employs an MQ135 sensor to keep the check on air quality around the farm, that's why it can dive into the concentrations unclean gases and preteens (fig 7).

Fig. 7. MQ135 Sensor.

The reading from the MQ135 sensor is logged in an Arduino Mega microcontroller where it can be used for alarms and/or saved.

4.7 DHT11 Sensor:

The DHT11 sensor is a key part of Smart Irrigation System and it records the temperature and humidity in real time (Fig 8).

Fig. 8. DHT11 Sensor

The data is gathered by the DHT11 and absorbed by the Arduino Mega which is displayed on an LCD output for easy monitoring.

4.8 Bluetooth Module (HC-05):

HC-05 Bluetooth module is a key component for a smart irrigation system to provide reliable communication between the irrigation system and mobile devices via wireless communication (fig 9).

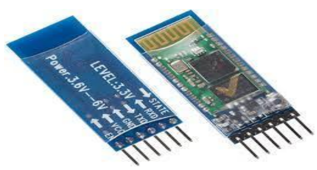

Fig. 9. Bluetooth Module (HC-05).

4.9 Relay:

Relay module in the Smart Irrigation System is much needed component to operate high voltage devices such as water pumps according to the instruction of microcontroller. This feature contributes for accurate and automatic regulation of irrigation (fig 10).

Fig. 10. Relay.

The relay effectively isolates the low-power control circuit from the high-power operating circuit to provide the security protection for the system.

4.10 GSM:

The GMS module in some irrigation system is important in transmitting over all status of the system like alarm and update. This facility is of particular use to farmers in outlying areas as timely notifications can save crops or the system (Fig 11).

Fig. 11. GSM

Coupled with an Arduino Mega microcontroller, the GSM module analyses data collected from the sensors and sends important data back to the users. time.

4.11 AC Water Pumping Motor:

AC water pumping motor The AC water pumping motor is a vital component for the smart irrigation structure that pumps water to the fields based on their real-time requirements. Thanks to the motor, water is delivered only if necessary minimising imbalances and environmentally friendly agriculture (Fig 12).

Fig. 12. AC Water Pumping Motor.

In the present work, the AC water pumping motor is interfaced with other sensors and devices, for obtaining active irrigation control. Such an arrangement provides not only optimal conditions for crop growth, but also requires less labor input, thus making the system a practical, resource saving alternative to modern farming problems.

4.12 LED:

The indication that plant needs water or the water tank is empty or full is given by LED's in Smart Irrigation System for the graphical representation (Fig 13).

Fig. 13. Led

In addition, the LED can also be utilized to demonstrate the wellbeing of the system or to signal possible issues to the user.

4.13 Nodemcu (ESP8266):

The data is available remotely as soon as the data is sent wirelessly through the NodeMCU module to ThingSpeak which is the core of the Smart Irrigation system (Fig 14).

Fig. 14. Nodemcu (ESP8266).

Aside from the cloud feature, the NodeMCU further provides the Smart Irrigation System with the capability to communicate with a mobile application via the Bluetooth HC in processing and relaying information about the sensors, the NodeMCU simplifies the control of the irrigation system and therefore becomes an important part of a more efficient and responsive farming system.

4.14 LCD:

The LCD in SIS serves as an important interface to present the real-time system s data (Fig 15).

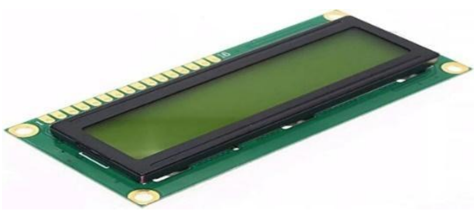

Fig. 15. LCD.

Apart from sensor data, the LCD provides an effective way to interact with the system. Advantages and Applications

Advantages

- Automation
- Remote monitoring
- Efficient water management
- Cost-effective

Applications

- Smart Farming
- Greenhouse Irrigation
- Urban Landscaping
- Home Gardening
- Precision Agriculture

5 Results

5.1 Soil Moisture and Light Intensity (LDR) Readings

Fig 16 shows the soil moisture and Light Dependent Resistor (LDR) values measured by the sensors.

- Soil Moisture Sensor: The soil moisture sensor data is critical for determining the water requirements of the plants. The system activates irrigation only when the soil moisture drops below a predefined threshold, ensuring water conservation. As shown in the results, when moisture levels were low, the irrigation system successfully activated and delivered water to the crops, preventing unnecessary water wastage.
- LDR Sensor: The LDR sensor measures the amount of sunlight available for photosynthesis, a vital process for plant growth. In the results, varying light conditions were recorded, ensuring the system adjusts the irrigation schedule according to sunlight availability. This adaptation helps prevent over-irrigation during sunny periods and reduces water usage.

Analysis: The combination of soil moisture and light intensity data helps the system determine the optimal irrigation time, ensuring both sufficient water and adequate sunlight for crop growth, thus contributing to resource conservation and higher crop yield.

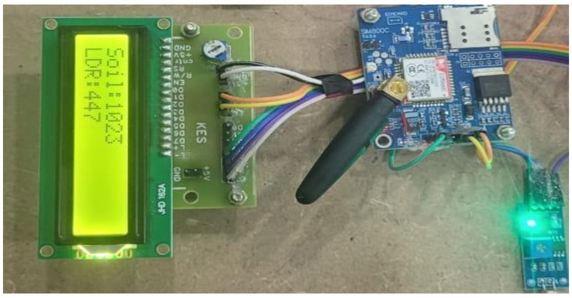

Fig.16. Soil moisture and LDR values measured by the sensors.

5.2 Temperature Alert

Fig 17 shows a high-temperature alert when the temperature exceeds a certain threshold.

- **Temperature Sensor**: The DHT11 temperature sensor is used to measure environmental temperature. In the results, when the temperature exceeded the set threshold, the system triggered an alert, ensuring that high temperature does not affect plant health. This could be especially useful in preventing heat stress in crops.

Analysis: By actively monitoring temperature fluctuations, the system can trigger timely actions, such as adjusting irrigation patterns or issuing alerts to the farmer to intervene. This feature is crucial in regions prone to temperature extremes, ensuring crops remain in optimal conditions.

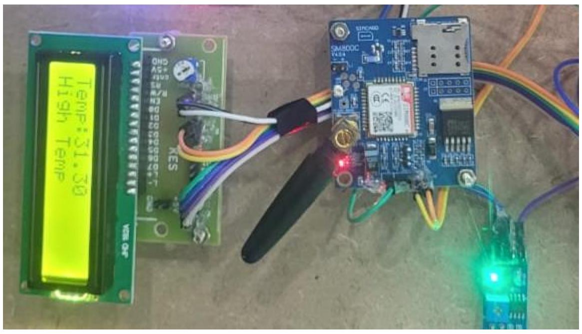

Fig.17. High-temperature alert when the temperature exceeds the threshold.

5.3 Disease Detection through Image Processing

Fig 18 and Fig 19 demonstrate the use of a USB camera for leaf disease detection.

- **Camera & Disease Prediction**: The USB camera captures images of the plant leaves, and the system uses image processing techniques to detect disease symptoms. In the results, the system successfully predicted leaf diseases and recommended the appropriate pesticide treatment. This feature is especially valuable for early disease detection, allowing farmers to act before widespread crop damage occurs.

Analysis: The integration of image-based disease detection adds significant value by reducing the time it would traditionally take for farmers to identify diseases. Real-time recommendations ensure that interventions are timely, minimizing crop loss and the need for excessive pesticide use.

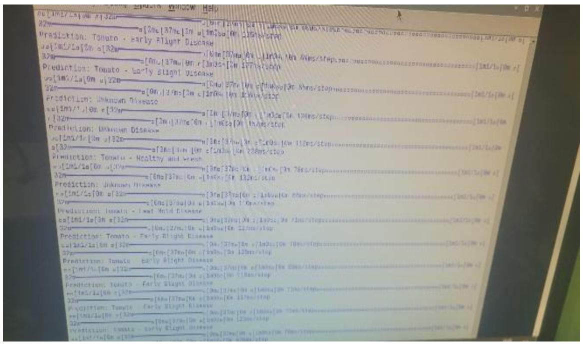

Fig.18. Output Screen of python which also predicts disease name.

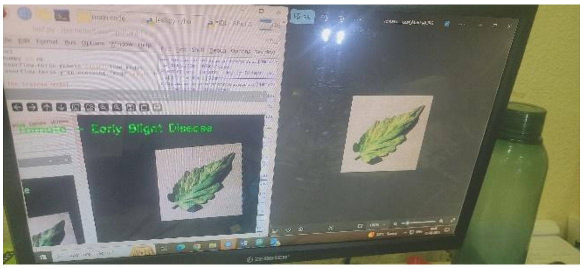

Fig. 19. Camera capturing leaf and detecting the disease.

5.4 pH Sensor for Water Quality Monitoring

Fig 20 displays the pH value, indicating an alkaline condition.

- **pH Sensor**: The pH sensor is used to monitor the quality of the water being supplied for irrigation. In the results, when the pH level was too high (alkaline), the system alerted the user. This ensures that only water with the correct pH is used, which is essential for optimal plant health.

Analysis: pH monitoring is vital, as improper water pH can lead to nutrient deficiencies or toxicities in plants. The pH sensor's integration ensures that the water quality remains within safe levels for plant growth, preventing long-term damage and reducing the need for chemical adjustments.

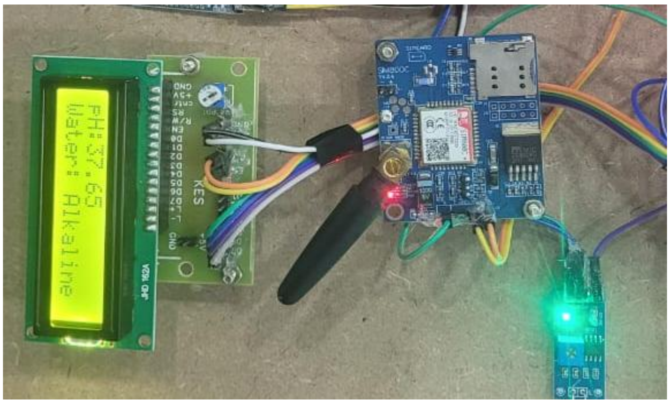

Fig. 20. pH value, indicating an alkaline condition.

Table 1 presents a summary of the experimental results, including measured sensor values, the predefined thresholds used by the system, and the corresponding system actions. This quantitative evidence supports the descriptive results discussed above.

Table 1. Experimental Results of Smart Irrigation System

Parameter	Measured Value	Threshold	System Action
Soil Moisture (%)	28	<30	Pump activated
Light Intensity (LDR, lux)	1200	>1000	Irrigation delayed
Temperature (°C)	38	>35	High-temp alert triggered
pH Value	8.1	>7.5	Water flagged as alkaline
Leaf Disease	Detected: Blight	N/A	Suggested pesticide: X

6 Conclusions

In conclusion, the Smart Irrigation System offers a comprehensive approach to efficient water management and sustainable farming by integrating various sensors to monitor soil moisture, water quality, environmental conditions, and plant health. Through automated control of irrigation and real-time data monitoring, it minimizes resource wastage, reduces the need for manual intervention, and ensures optimal conditions for crop growth. The system's ability to provide alerts and data remotely via GSM and mobile app communication further enhances its practicality and effectiveness, making it a valuable tool for modern agricultural practices.

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