Smart Harvesting System (Agro-Flow)

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Abstract This research presents the development of an integrated Internet of Things (IoT)-based agricultural system that automates plant watering and monitors crop health to enhance farming efficiency and sustainability. The first component of the system is an automatic plant watering system, which leverages soil moisture sensors to monitor real-time soil conditions. When the soil moisture level falls below a predefined threshold, the system triggers an automatic irrigation process via a water pump. This system can be remotely controlled and monitored through a smartphone application or web interface, ensuring optimal water usage and preventing over-watering or under-watering. The second component, the crop health indicator, uses a combination of environmental sensors (temperature, humidity, soil pH, light intensity) and advanced imaging technologies such as multispectral cameras or drones to assess crop health. These sensors detect critical factors affecting plant growth and yield, such as disease, pest infestation, or nutrient deficiencies. The data collected from these sensors is processed in real-time and analyzed to provide actionable insights and timely alerts to farmers, enabling them to take appropriate actions to address crop stress and optimize yield. The system is designed to be user-friendly, providing farmers with easy access to critical data and control through mobile and web interfaces. The integration of these technologies aims to reduce resource consumption, enhance crop productivity, and support sustainable agricultural practices.

Keywords. IoT, automatic irrigation, crop health monitoring, soil moisture sensor, real-time data analysis.

INTRODUCTION

The integration of Internet of Things (IoT) technologies into agriculture has emerged as a promising solution to address critical challenges related to resource management, crop health, and sustainable farming practices. With the growing global population and the increasing demand for food, agriculture must become more efficient, both in terms of water usage and crop management. Traditional irrigation methods often lead to water wastage or under-irrigation, resulting in suboptimal crop growth and increased operational costs. Similarly, the manual monitoring of crop health, including factors like soil moisture, temperature, and pest infestations, is labor-intensive and prone to errors. These inefficiencies highlight the need for automated systems that can monitor real-time conditions and optimize resource usage.

This research proposes the development of an IoT-based agricultural system aimed at automating irrigation and continuously monitoring crop health. The first component of the system focuses on automating irrigation based on real-time soil moisture readings, ensuring efficient water usage and preventing over- or under- watering. The second component uses IoT sensors, including environmental and multispectral imaging devices, to continuously monitor the health of crops and detect signs of disease, pest infestation, or nutrient deficiencies. By integrating these two systems into a cohesive platform, the research aims to improve farm productivity, reduce water wastage, and enable early intervention to safeguard crop health.

The importance of this research lies in its potential to address key challenges in modern agriculture. Recent studies have highlighted the inefficiencies of traditional irrigation methods and the increasing need for precision agriculture to cope with environmental and economic pressures [1], [2]. The proposed system offers a solution to these issues by combining automation and real-time monitoring. The objectives of this work are to reduce resource wastage, improve crop yields, and make farm management more efficient through the use of IoT technologies. This work contributes to the ongoing development of smart agriculture solutions by integrating key technologies for both irrigation management and crop health monitoring, offering a comprehensive and scalable solution for modern farming [3].

RESEARCH METHODOLOGY

The research methodology for the IoT-based agricultural system focuses on the development and implementation of automated irrigation and crop health monitoring systems using real-time data collection, IoT devices, and wireless communication. The methodology is divided into two main components: the design and implementation of the automated irrigation system and the crop health monitoring system.

- **Automated Irrigation System Design** The automated irrigation system relies on soil moisture sensors, which continuously measure the soil's moisture content. The system works by detecting the moisture levels of the soil and comparing them to predefined thresholds. When the soil moisture falls below the threshold, the system automatically activates the water pump to irrigate the plants. The water pump is controlled through a relay module connected to the NodeMCU (ESP8266) microcontroller, which sends a control signal based on the sensor data. The irrigation process is designed to be energy-efficient and water-conserving by ensuring that the system operates only when necessary.

Steps involved in the automated irrigation system:

Step 1: **Sensor Calibration**: Soil moisture sensors are calibrated by defining a baseline moisture level for the specific soil type used in the experiment.

Step 2: **Threshold Setting**: Predefined moisture thresholds are set based on the crop’s irrigation requirements. These thresholds help determine when irrigation should be triggered.

Step 3: **Data Collection**: The soil moisture sensor continuously monitors the moisture content of the soil and sends the data to the NodeMCU microcontroller.

Step 4: **Relay Control**: The microcontroller processes the data from the sensor and activates the relay, which in turn triggers the water pump to irrigate the plants when the moisture level falls below the set threshold.

- **Crop Health Monitoring System** The crop health monitoring system uses various IoT sensors, including temperature, humidity, and light sensors, to monitor the environmental conditions that affect crop health. Additionally, multispectral imaging sensors or cameras are utilized to capture visual data for disease detection, pest monitoring, and nutrient deficiency analysis. Data from all sensors is transmitted wirelessly to the NodeMCU, which processes the information and sends it to a cloud-based platform or a mobile app for remote monitoring.

Steps involved in the crop health monitoring system:

Step 1: **Environmental Sensors**: Temperature and humidity sensors (e.g., DHT22) are used to monitor the environmental conditions around the crops. The data from these sensors are sent to the NodeMCU for processing.

Step 2: **Light Intensity Measurement**: A light-dependent resistor (LDR) is used to measure the amount of sunlight available to the plants. The LDR's output helps assess whether the crops are receiving sufficient light for photosynthesis.

Step 3: **Disease Detection**: Multispectral cameras or drones equipped with imaging sensors capture high-resolution images of the crops. These images are analyzed using software to detect any anomalies or early signs of pest infestation or disease.

Step 4: **Data Processing and Analysis**: All sensor data (moisture, temperature, humidity, light) and image data from the multispectral sensors are processed by the NodeMCU. The microcontroller evaluates the conditions and triggers alerts to the user (farmer) if any crop health issues or irrigation requirements are detected.

- **Wireless Communication and Data Transmission** The data from both the irrigation system and the crop health monitoring system is transmitted wirelessly using Wi-Fi, facilitated by the NodeMCU microcontroller. The NodeMCU is connected to the internet, and all collected data is sent to a cloud-based platform or smartphone app for remote monitoring. The system ensures that farmers can receive real-time updates and alerts on their mobile devices, allowing them to take immediate action when needed.

Wireless communication steps:

Step 1: **Cloud Integration**: The NodeMCU sends the processed data from the sensors to a cloud- based server or platform (e.g., Blynk, ThingSpeak) for storage and analysis.

Step 2: **User Interface**: The data is displayed on a mobile application or web interface, which provides the user with real-time monitoring capabilities. The user can view the soil moisture level, environmental conditions, and receive notifications on crop health issues.

- **System Testing and Validation** Once the system is developed, it undergoes rigorous testing to ensure its functionality and reliability. The following testing phases are carried out:
  1. **Sensor Calibration Test**: To ensure that the sensors are providing accurate readings, calibration is performed by comparing sensor data against known standards.
  2. **Irrigation Trigger Test**: The system is tested by simulating different soil moisture levels and verifying that the irrigation system activates correctly when moisture falls below the set threshold.
  3. **Crop Health Monitoring Validation**: The crop health monitoring system is tested by assessing its ability to detect changes in environmental conditions and crop health (e.g., temperature, humidity, and pest infestation).
  4. **System Integration Test**: The complete IoT system, including both the irrigation and crop health monitoring components, is tested to ensure proper communication between sensors, the microcontroller, cloud platform, and mobile app.
- **Data Analysis and Performance Evaluation** The performance of the IoT-based agricultural system is evaluated based on several criteria:
  1. **Water Usage Efficiency**: The amount of water saved by the automated irrigation system is measured and compared to traditional irrigation methods.
  2. **Crop Yield**: The crop health data, including temperature, humidity, and disease detection, is analyzed to evaluate improvements in crop yield and quality.
  3. **System Reliability**: The reliability of the entire system is assessed through long-term testing to ensure that sensors provide accurate data and the system operates consistently over time.

LITERATURE SURVEY

Source	Journal/Conference	Focus Area	Limitations
Jalgaon et al. (2017)	International Journal of Advanced Research in Computer Science	Automated irrigation using soil moisture sensors	Limited to soil moisture; no integration with other factors like weather data
Patel et al. (2018)	International Journal of Computer Applications	Dynamic irrigation based on soil moisture and weather forecasts	Weather data may not always be accurate or available
Kumar et al. (2020)	Computers and Electronics in Agriculture	Crop health monitoring using environmental sensors and infrared cameras	Limited detection types, relies on specific plant behaviors
	Journal of Agricultural and Food Chemistry	Drone-based crop health monitoring using multispectral imaging	
Nayak et al. (2021)	International Journal of Advanced Computer Science and Applications	Real-time data collection and alerts for environmental Conditions	Limited to basic sensors, lacks machine learning integration

THEORY AND CALCULATION

The integration of Internet of Things (IoT) technology into agriculture involves the application of several key theoretical principles in both automation and monitoring. These principles are grounded in sensor technology, wireless communication systems, and data analysis. This section elaborates on the theoretical foundations that support the design and implementation of the automated plant watering system and crop health indicator. The following theoretical concepts form the basis for the system's design and subsequent calculations.

Soil Moisture Sensing and Irrigation Automation

The core principle of the automated irrigation system is the measurement and management of soil moisture. Soil moisture sensors typically operate on the principle of electrical resistance or capacitance. A **resistive sensor** measures the resistance between two electrodes embedded in the soil, which correlates with the moisture content. As the moisture content increases, the resistance decreases, providing a direct measurement of soil wetness. The relationship between soil moisture and irrigation needs is modeled using a moisture threshold below which the system is triggered to initiate watering.

The calculation for triggering irrigation can be expressed as:

$$Irrigation\,Trigger = Soil\ Moisture < Threshold\ Moisture$$

Where:

- **Soil Moisture** is the real-time data input from the soil moisture sensor (typically an analog signal converted to a digital reading).
- **Threshold Moisture** is the predetermined moisture level at which the system activates irrigation.

This formula ensures that irrigation occurs only when soil moisture falls below an acceptable range, thus conserving water while ensuring the crops receive adequate hydration.

Crop Health Monitoring via Environmental Sensors

Crop health is influenced by several environmental factors, including temperature, humidity, light intensity, and soil pH. These variables are continuously monitored using sensors like the **DHT11/DHT22** for temperature and humidity, and **LDR** for light intensity. The system calculates ideal conditions for different crops, and deviations from these conditions are used to generate alerts for potential crop stress.

The health of the crop can be modeled using a simple formula combining multiple environmental factors:

$$Crop\ Health = f(Temperature, Humidity, Light, Soil\ pH)$$

Where:

- **Temperature**, **Humidity**, and **Light** are real-time data inputs from their respective sensors.
- **Soil pH** is an additional factor influencing plant health, which can be measured using a pH sensor.

The system's decision-making logic evaluates the combined values of these inputs to detect abnormalities or stresses. For instance, high humidity combined with low light intensity may indicate a potential risk for fungal diseases, prompting the system to send an alert to the farmer.

Mathematical Expressions and Symbols

1. Data Communication and Remote Monitoring

Data communication in this IoT system relies on wireless protocols, mainly Wi-Fi. The **NodeMCU** microcontroller acts as the central processing unit, receiving data from various sensors and transmitting it via Wi-Fi to a cloud platform or smartphone application. The calculation of the optimal communication range is crucial for ensuring reliable data transmission.

The communication range and signal strength can be modeled using the **Friis transmission equation**:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

- **P_r** is the received power,
- **P_t** is the transmitted power,
- **G_t** and **G_r** are the gains of the transmitting and receiving antennas,
- **λ** is the wavelength of the signal,
- **d** is the distance between the antennas.

The formula is used to estimate the strength and reliability of the signal between the NodeMCU and the mobile device or cloud server, ensuring that data is transmitted in real-time with minimal delay.

2. Relay Control and Motor Activation

The relay module in the system serves as the switch that controls the water pump. The relay is activated by the microcontroller based on the calculated soil moisture levels. The theoretical operation of the relay involves the logic gate that triggers the motor when the soil moisture value falls below the predefined threshold.
The relay control operation can be described by a Boolean equation:

$$Relay\ State = Soil\ Moisture < Threshold\ Moisture$$

When the condition is met (i.e., the soil moisture falls below the threshold), the relay is activated, completing the circuit and triggering the water pump to start.

3. Calculations for System Efficiency and Water Conservation

One of the key goals of the IoT-based system is to conserve water while maintaining optimal crop health. The system's efficiency can be evaluated based on the amount of water used per crop and compared to traditional irrigation methods. The efficiency can be calculated using the following formula:

$$Water\ Efficiency = \frac{Amount\ of\ Water\ Used}{Crop\ Yield}$$

By monitoring the total water usage and crop output, the system can be optimized over time, adjusting the irrigation thresholds and schedules based on real-time data.

RESULTS AND DISCUSSIONS

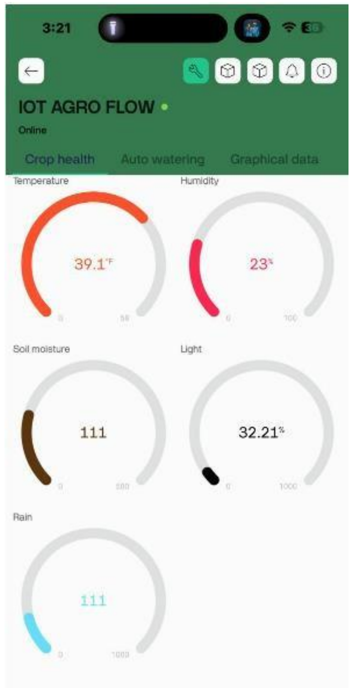
All the results are collected at the blynk iot application which should be installed at mobile and thee data should be collected and shown on this application. The interface shows three divisions which are

a) Crop Health
b) Auto Watering
c) Graphical Data

The below image shows a mobile app interface for an IoT-based agriculture system called "IOT AGRO FLOW". The app displays real-time data on various crop health parameters:

- Temperature: Current temperature is 39.1°F.
- Humidity: Current humidity is 23%.
- Soil Moisture: Current soil moisture is 111.
- Light: Current light intensity is 32.21%.
- Rain: Current rainfall is 111.

The app also offers features like auto-watering and graphical data visualization.

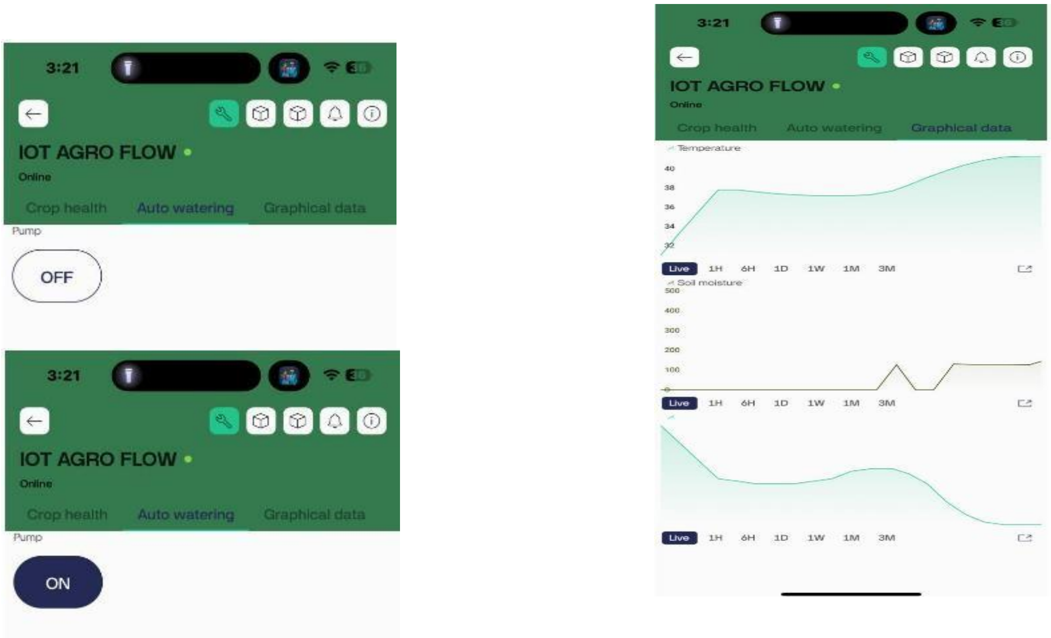


The below image shows the "Auto Watering" section of the IoT AGRO FLOW app. The "Pump" button being "ON" indicates that the automatic watering system is currently active.

Here's how the soil moisture sensor works to control the water flow:

* Soil Moisture Sensor: The system is equipped with a soil moisture sensor that is placed near the plant roots. This sensor constantly measures the moisture content of the soil.
* Moisture Level Monitoring: The app continuously receives data from the sensor and monitors the soil moisture levels.
* Threshold Setting: The user can set a desired moisture level threshold in the app. This threshold determines the level at which the automatic watering system should activate.
* Automatic Watering: When the soil moisture level falls below the set threshold, the app triggers the automatic watering system. This system could be a pump or a drip irrigation system connected to the app.
* Water Flow Control: The system then starts delivering water to the plant until the soil moisture level reaches the desired threshold. Once the threshold is reached, the water flow is automatically stopped.

By using this sensor-based system, the app ensures that the plant receives the right amount of water at the right time, preventing both overwatering and underwatering.



a) b)

The below image shows a mobile app interface for an IoT-based agriculture system called "IOT AGRO FLOW". The app displays real-time data on various crop health parameters, specifically temperature, soil moisture, and rainfall over different time intervals (1 hour, 6 hours, 1 day, 1 week, 1 month, and 3 months). The app also offers features like auto-watering and graphical data visualization.

The below image shows an alert notification sent from the Blynk app to the user's phone. The alert is titled "moisture_alert" and informs the user that the soil moisture level has fallen below the set threshold.

Here's what the notification means:

Soil Moisture Level: The soil moisture sensor is monitoring the moisture content in the soil where the plant is growing.

- Threshold: The user has set a minimum moisture level threshold in the Blynk app. This threshold represents the desired level of soil moisture for the plant.
- Alert Trigger: When the soil moisture level drops below this threshold, the Blynk app sends an alert notification to the user's phone.

The notification serves as a reminder to the user that the plant needs water. The user can then take appropriate action, such as manually watering the plant or checking the automatic watering system. This feature of the Blynk app helps ensure that the plant receives adequate water and remains healthy.

FUTURE SCOPE AND IMPROVEMENTS

The current IoT-based agricultural system provides a foundation for smart farming practices, especially in automating irrigation and monitoring crop health. However, there are several areas where future improvements and expansions can be made to enhance its efficiency and scalability.

- **Advanced Sensors for Precision Agriculture**

One of the significant areas of improvement lies in the deployment of more advanced sensors that can monitor a broader range of environmental factors. Future systems could integrate sensors that detect nutrient levels, soil texture, and plant health via spectroscopy. These sensors could provide more granular data to ensure crops receive the right type and amount of nutrients, optimizing growth and minimizing the use of fertilizers and water.

- **Integration of Machine Learning and AI**

Machine learning (ML) and artificial intelligence (AI) could play a crucial role in improving the decision-making process in agriculture. The current system relies on preset thresholds and simple sensor data for triggering irrigation and crop health interventions. Future work could involve integrating ML algorithms to predict optimal irrigation schedules based on historical data, weather patterns, and soil conditions. Additionally, AI models can be used for advanced disease detection and pest management by analyzing multispectral images from drones or cameras and providing more accurate diagnostics.

- **Expansion to Large-Scale Agriculture**

While the current system is designed for small to medium-scale farms, it can be expanded to cater to large-scale agricultural operations. This would involve improving the system's scalability by enhancing communication protocols to handle large volumes of data, as well as expanding its ability to manage large numbers of sensors and actuators in a seamless manner. Using cloud computing and edge computing will further help manage data processing efficiently and in real- time.

- **Energy Efficiency and Solar Integration**

An important future development would be to integrate renewable energy sources, such as solar panels, to power the sensors and actuators, making the system more energy-efficient and sustainable. This would be particularly useful for remote farming areas where the availability of a stable electrical grid is limited. Solar-powered sensors and low-power actuators would ensure that the system remains operational in an environmentally friendly way, further promoting the sustainability of modern agriculture.

- **Real-Time Data Analytics and Visualization**

Future enhancements could involve more advanced data analytics platforms that can analyze real- time sensor data and provide actionable insights to farmers in a more user-friendly manner. The incorporation of advanced data visualization techniques and dashboards will allow farmers to make quicker decisions and intervene in case of any anomalies. This could include machine learning- based forecasting for crop yield predictions, disease spread, and water usage optimization.

CONCLUSION

The IoT AGRO FLOW system, as depicted in the provided images, presents a promising solution for modern agriculture. By leveraging IoT technology, it enables real-time monitoring of crucial crop health parameters and automated control of irrigation systems.

The system's ability to collect and analyze data from various sensors allows farmers to make informed decisions, optimize resource utilization, and improve crop yields. Additionally, the remote monitoring and control features offer flexibility and convenience.

However, to fully realize its potential, addressing the limitations and implementing the suggested improvements is crucial. By prioritizing sensor reliability, network connectivity, power management, user-friendliness, and security, the system can become a valuable tool for sustainable and efficient agriculture.

As technology continues to advance, further integration of AI and machine learning can unlock even greater opportunities for precision agriculture, enabling predictive analytics, automated decision-making, and optimized crop management practices.

DECLARATIONS

Study Limitations

This study on the IoT-based Agro Flow Project, which integrates automated irrigation and crop health monitoring, faces several limitations that could influence the overall outcomes. The accuracy of the system relies heavily on the performance and reliability of the sensors (soil moisture, temperature, humidity, and rain sensors). Inconsistent sensor calibration or hardware malfunctions may affect data accuracy, which in turn could result in suboptimal irrigation or inaccurate health assessments of crops. Furthermore, the system's dependency on Wi-Fi connectivity may lead to issues in rural areas where network availability is limited or unreliable. The scalability of the system to larger agricultural areas, particularly with numerous sensors distributed over wide fields, has not been fully tested. While the system is effective for small-scale setups, challenges may arise when scaling up for larger, more complex agricultural environments. Lastly, the system's performance may be influenced by extreme weather conditions, and long-term testing across different seasonal conditions was not performed. These factors need further investigation in future studies.

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Competing Interests

The authors declare that there are no conflicts of interest related to the publication of this manuscript. The research was conducted in an independent manner, and no commercial interests or affiliations have influenced the findings or conclusions presented in the study.

Human and Animal Related Study

Since this research does not involve any human or animal subjects, the following applies:

Ethical Approval

As the study did not involve human or animal subjects, ethical approval was not required.

Informed Consent

Informed consent was not applicable as no human participants were involved in the study. The research focused solely on the development and testing of an IoT-based system for agricultural use.

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