IoT Based Plant Nutrition Detection Optimizing Plant Health with IoT-Enabled monitoring systems

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Abstract— **Through the collection and analysis of data on soil nutrient levels and environmental conditions, the IoT system can detect nutrient deficiencies, imbalances, or excesses, providing farmers with actionable insights for precision fertilization. The system employs machine learning algorithms to interpret sensor data and provide recommendations for optimizing plant nutrition and improving crop yield. Additionally, it supports real-time alerts, allowing farmers to take timely corrective actions, thereby reducing the use of chemical fertilizers and promoting sustainable agricultural practices.**

I. INTRODUCTION

The Internet of Things (IoT) is transforming agriculture by introducing cutting-edge technologies for monitoring and enhancing crop health. Among these innovations, IoT-based plant nutrition detection systems stand out as an essential tool for ensuring plants receive the right nutrients at the right time. These systems provide real-time data and actionable insights, enabling farmers to optimize their resources, improve crop yields, and adopt more sustainable farming practices.
Traditional methods for assessing plant nutrition, such as soil testing and visual inspections, can be time-consuming, labor-intensive, and prone to inaccuracies. IoT-based solutions address these challenges by integrating advanced sensors, wireless connectivity, and cloud-based data analytics. These systems measure critical parameters such as soil moisture, electrical conductivity, temperature, and nutrient concentrations like nitrogen, phosphorus, and potassium. By transmitting this data to cloud platforms, IoT systems enable continuous monitoring and sophisticated analysis, providing users with precise insights into the nutritional needs of their crops.

One of the major advantages of IoT-based plant nutrition detection is real-time monitoring, which allows farmers to address nutrient deficiencies or imbalances before they affect plant health. This capability supports precision agriculture, where inputs like fertilizers and water are applied in just the right amounts, reducing waste and minimizing environmental impact. Additionally, IoT automation reduces labor costs and enhances cost efficiency while contributing to improved crop yields and sustainability. Alerts and recommendations provided through intuitive dashboards or mobile apps empower users to make timely and informed decisions.

II. RELATED WORK

Few attempts have been made in the past to recognize the needs of the plant but with limitations of recognition rate and time which includes:

1. IoT-based intelligent monitoring for efficient management in smart agriculture.
2. Smart Farming Pot
3. Sensor Networks for Plant Monitoring.

In IoT-based intelligent monitoring had deployed a sensor network in a greenhouse to monitor temperature, humidity, and soil conditions, which resulted in a 30% reduction in water usage while maintaining optimal plant growth. By automating irrigation and fertilization processes, the system reduced resource waste and improved plant growth.

Disadvantage: Highly expensive, and inaccurate.
In smart farming pot they cover requirement of water, requirement of fertilizer, requirement of sunlight confined to this specific plant. It is a pot that can detect the presence of sunlight and water when the quantity of these two things goes beyond the minimum defined limit, then the LED glows. It also gives an alert if it requires water and sunlight. Then we will use water level sensor and based on that sensor output we will drive our motor to supply water to the plant.
Disadvantage: This is only suitable to detect amount of sunlight required and water content in the soil

In plant monitoring, they deployed a sensor network in a greenhouse to monitor temperature, humidity, and soil conditions, which resulted in a 30% reduction in water usage while maintaining optimal plant growth.

Disadvantage: It was implemented for closed space and just monitoring.

III. BACKGROUND

Conventional agriculture's productivity remains low due to the continued use of traditional nutrient management methods, which are primarily based on soil analysis results and the observation of nutrient deficiency symptoms, with nutrient application determined by the plant's growth stage. The advancement of agricultural technology, such as the Internet of Things (IoT), has facilitated both plant and soil analysis. The IoT represents a significant advancement within the area of the Internet by integrating computing devices into everyday things, allowing them to autonomously gather and send data [1]. The implementation of IoT will streamline soil and plant nutrition management for farmers and increase the productivity of agriculture.

Over the years, farmers have traditionally relied on their knowledge of essential nutrients or conducted soil sampling analysis in the laboratory using various techniques, such as the destructive method. However, the sampling analysis process has several limitations, including being time-consuming and labor- intensive [2]. In line with the advancements in modern agriculture, sensor technology has emerged as an innovation, offering a nondestructive method for assessing nutrient statuses and enabling real-time monitoring. The integration of data analysis, remote sensing, and smart machinery has played a pivotal role in the evolution of nutritional management practices [3]. The application of IoT to nutrient management has shown promising results that align with crop requirements [4, 5], and it is important to note that these findings should be interpreted with caution since not all the studies have been reported with the plant-tested on a large scale.

Water and nutrient management in crop systems traditionally relies on timers to regulate watering periods, but they are often ineffective during rainy days [6]. To address this problem, precision agriculture can be developed to optimize the usage of water and fertilizer [7]. This system consists of several essential components, such as sensors, microcontrollers, connectivity, and actuators. Although it is not commonly used by local farmers, showcasing its potential to reduce labor and increase yields compared to traditional methods can increase the level of acceptance.

Water and nutrients are basic requirements for crop development, and their unavailability often leads to growth deficiency. Nutrient management involves supplying minerals that align with the specific requirements of crops [8]. Although there are many research targeted at assuring optimal nutrient management, most of them are still in the prototype stage and have not been field tested. Researchers frequently use two study methodologies: experimental and prototype design, tested with or without the plants. Furthermore, general practices that can be applied across all crop platforms should be developed to make smart agriculture a considerable alternative for local farmers. This paper seeks to provide a comprehensive evaluation of soil nutrient management implementation and the related constraints. Furthermore, it endeavors to tackle the imminent challenges associated with implementing soil management systems aimed at promoting sustainable crop productivity.

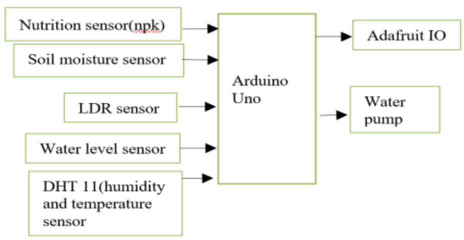

Fig-1: Hardware components

IV. METHODOLOGY

1. System Design & Planning: Understand the need for plant nutrition monitoring and automated irrigation to improve farm productivity. Choose sensors and microcontrollers based on the parameters to be monitored: Soil moisture sensor, NPK sensor, DHT11 ,LDR and water level sensor. Arduino for local processing and NodeMCU ESP8266 for Wi-Fi communication.
2. Hardware Integration: Connect the sensors to the Arduino using the appropriate analog or digital pins. Program the Arduino to read the sensor values and control the relay to activate the water pump when necessary. Use NodeMCU ESP8266 to communicate with the cloud by transmitting data from Arduino.

3. Data Collection: Program the Arduino to gather data from the sensors. Process raw data into usable information. NodeMCU sends processed data to Adafruit IO using the MQTT protocol for storage.
4. Generate Suggestions: If soil moisture is low, the system will automatically activate the water pump and/or suggest irrigation. If NPK levels indicate deficiencies. Based on temperature and light data, the system can recommend adjustments to the farming environment.
5. Web Application Development: Dashboard Creation: Set up real-time data feeds for each sensor on Adafruit IO . Provide options for users to set thresholds, view historical data, and receive alerts.
6. Testing & Validation: Test each sensor individually to ensure accurate readings. Verify that the relay properly controls the water pump based on the soil moisture level. Ensure the data from Arduino is correctly transmitted to the cloud and displayed on the dashboard. Test the entire system in real-world conditions, such as in a garden or farm, and ensure it automatically adjusts irrigation and provides correct suggestions.

Deployment & Monitoring: Deploy the system in an agricultural field to monitor plant health and manage irrigation. Provide user training to explain how to interact with the dashboard, set thresholds, and monitor the system. Enable remote monitoring through the cloud platform, where farmers can check the health of their crops and soil from anywhere.

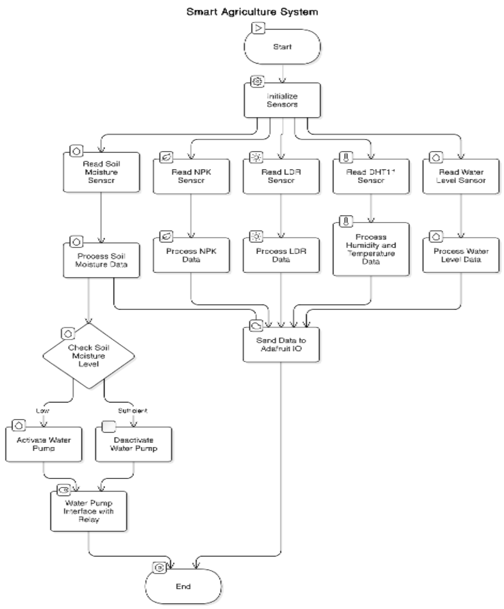

Fig. 2. Flow chart of algorithm

Mathematical Explanation:

To create a robust system, we need mathematical models for interpreting sensor data, analyzing trends, and automating decisions. Here's a breakdown of the mathematics involved:

1. NPK Sensor

The NPK sensor provides voltage signals proportional to the concentration of nitrogen (N), phosphorus (P), and potassium (K).

Formula:

C_{NPK} = \frac{V_{\text{out}}}{V_{\text{max}}} \times R_{\text{max}}

: Nutrient concentration (ppm).

: Sensor output voltage.

: Maximum voltage range of the sensor (e.g., 5V).

: Maximum measurable nutrient range (ppm).

Example: If , , and :

C_{NPK} = \frac{2.5}{5} \times 500 = 250 \, \text{ppm}

2. Soil Moisture Sensor

The soil moisture sensor provides an analog reading proportional to soil moisture content.

Formula:

\text{Moisture (\%)} = \frac{A_{\text{read}} – A_{\text{dry}}}{A_{\text{wet}} - A_{\text{dry}}} \times 100

: Current sensor reading

\text{Moisture (\%)} = \frac{400 - 200}{800 - 200} \times 100 = 33.3\%

3. DHT11 Sensor

The DHT11 sensor measures temperature () and relative humidity () directly.

Formula (Heat Index):

The heat index () combines temperature and humidity to measure the effect of heat on plants:

HI = -8.7847 + 1.6114T + 2.3385H - 0.1461TH + 0.0123T^2 + 0.0164H^2 - 0.0022T^2H

: Temperature (°C).

: Relative Humidity (%).

Example: For , :

HI = -8.7847 + 1.6114(30) + 2.3385(60) - 0.1461(30)(60) + 0.0123(30)^2 + 0.0164(60)^2 - 0.0022(30)^2(60)

HI \approx 34.5^\circ C]

4. Water Level Sensor

The water level sensor provides voltage proportional to the depth of water.

Formula:
\text{Water Level(\%)}=
\frac{V {\text{out}}}{V {\text{max}}} \times 100
:Sensor output voltage.
:Maximum sensor voltage(e.g.,5V).
Example: If and:
\text{Water Level(\%)}=\frac{3.0}{5.0}\times 100=60\%

5. Automation Decision(Irrigation System)

An automated irrigation system uses thresholds for moisture and water levels.
Decision Logic:
1. If : Turn on the pump.
2. If : Alert for low water reservoir.

6. Cloud Integration and Data Normalization

To send consistent data to the cloud, normalization is applied to map sensor readings to a 0–1 range.
Formula (Min-Max Normalization):
N = \frac{X - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}}
: Normalized value.
: Current sensor reading.
: Minimum sensor range.
: Maximum sensor range.
Example: For soil moisture , , :
N = \frac{400 - 200}{800 - 200} = 0.33

V. RESULTS

TABLE I. NUTRITION RANGE

Nutritions	Range
Nitogen	b/w 20-50 mg/kg
Potassium	b/w 100-250 mg/kg
Phosphorous	b/w 10-35 mg/kg

The following presents the results and discusses the effectiveness and potential challenges of the system.

1. Sensor Performance :

- Soil Moisture Sensor: The soil moisture sensor successfully provided real-time data, accurately measuring the moisture content in different soil types. It responded quickly to changes in irrigation, enabling timely activation of the irrigation system.
- NPK Sensor: The NPK sensor provided valuable insights into the nitrogen, phosphorus, and potassium levels in the soil. The system provided actionable data that allowed for precise nutrient management, improving crop growth by targeting specific deficiencies.

Fig.3. NPK sensor

- Temperature and Humidity Sensors: DHT11, operated effectively in detecting environmental changes. However, their accuracy was slightly influenced by direct sunlight exposure, requiring strategic placement to avoid skewed readings. The data collected helped adjust microclimate conditions for optimal plant growth.
- Light Sensor: The LDR sensor was highly sensitive to variations in light levels, contributing to an understanding of how much sunlight the plants received during the day. This information was integrated into the overall system for adjusting artificial lighting if necessary, ensuring optimal photosynthesis.

Fig.4. Code

2. System Performance and Data Communication:

- The communication between the sensors, microcontroller and cloud platform (Adafruit) was reliable and efficient. The Arduino, with built-in Wi-Fi, facilitated seamless data transmission from the field to the cloud.
- Once the data reached the cloud, it was stored in Adafruit databases and analyzed using basic algorithms to detect anomalies (e.g., low moisture or nutrient deficiencies). The system also provided predictive insights, such as estimating the next irrigation cycle or fertilizer application, based on historical data.

Fig.5. Working Model

3. Irrigation Automation: Based on the soil moisture readings, the system activated water pumps when the moisture levels fell below the threshold. This not only ensured that the plants received the appropriate amount of water but also saved water by avoiding over-irrigation.

Fig.6. Result on Adafruit

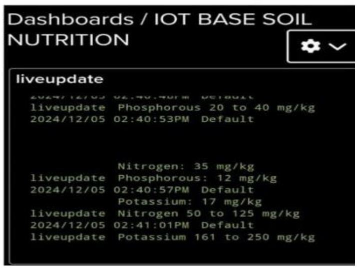

Fig.7. Output

The system's impact on crop yield and resource efficiency was measured over a trial period. By optimizing irrigation and nutrient management based on real-time data, resource use was significantly reduced. Water usage decreased by approximately 30%, and the need for chemical fertilizers was minimized by ensuring that nutrients were only applied when necessary. This not only improved crop health but also contributed to more sustainable farming practices. The data collected also allowed for continuous optimization of farming practices, enabling farmers to adjust their strategies based on observed trends, such as the correlation between soil pH and plant growth.

VI. CONCLUSION

The implementation of an IoT-based plant nutrition detection system represents a significant advancement in precision agriculture, enabling real-time monitoring of soil and environmental conditions. By integrating various sensors (such as soil moisture, NPK, and light sensors) with microcontrollers, communication modules, and cloud platforms, this system provides valuable insights into plant health and nutrient requirements. Through automation, it optimizes water and fertilizer usage, improving crop yields while reducing environmental impact and resource wastage. Additionally, the use of machine learning algorithms for predictive analysis further enhances the efficiency of these systems, enabling smarter, data-driven decisions in agricultural management. This IoT-based solution not only aids in maximizing productivity and sustainability but also empowers farmers with the tools they need to address challenges like climate change, resource scarcity, and soil degradation. As the technology continues to evolve, its integration with other emerging technologies such as AI, edge computing, and autonomous systems promises to offer even more robust and efficient solutions.

VII. REFERENCES

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These references include a combination of academic articles, case studies, and technical documentation that cover the various components and applications of IoT in agriculture, including sensor integration, cloud computing, machine learning, and automation for smart farming.