IoT based Soil Testing System with Recommendation of Organic Fertilizer

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Abstract

The research is about the proposed IoT-based soil testing system that focuses on improving soil quality by providing custom organic fertilizer recommendations and crop suggestions based on real-time soil analysis. The system makes use of a network of sensors, including moisture sensors and temperature and humidity sensors, to measure critical soil parameters. These readings are collected and processed using a Node MCU, which forms the basis of the data acquisition process. The data collected are analyzed with a machine learning approach. Initially, sensor readings are processed using the Random Forest algorithm to predict soil nutrient composition in terms of nitrogen (N), phosphorus (P), and potassium (K). Then, these values of nutrients are input into the Euclidean distance algorithm, which calculates the similarity that exists between the soil's current condition and a defined dataset of ideal soil profiles. The results on the suggested organic fertilizer and available crops are rendered on an easily accessible webpage that is user-friendly for farmers to use.

Keywords: IoT, Node MCU, NPK value, crops, fertilizer.

1. Introduction

The research describes about the soil testing system for IoT that improves soil quality through sustainable agriculture. This device makes real-time suggestions of appropriate organic fertilizers and crops, taking into consideration specific soil parameters such as

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moisture, temperature, and humidity. This approach addresses the inefficiencies of conventional methods, that often lead to soil degradation and reduced crop yields [1,2] The proposed system is cost-effective, easy to deploy, and supports precision agriculture by enabling timely interventions and optimized resource utilization. Some applications of this are assisting agricultural research institutions, small-scale organic farms, and government agricultural programs, advancing smart farming initiatives, and aiding soil restoration research. This solution is not only helpful in increasing the crop yield but also promotes the long-term soil health and environment sustainability, helping to make farming more resilient and productive [3]

2. Literature Survey

The application of IoT technologies has brought about a significant transformation in how famers should monitor soil and optimize agricultural resources. Researchers have demonstrated the efficacy of IoT-based smart systems for real-time monitoring and fertilizer optimization. These studies highlight the value of soil sensors that measure parameters like moisture and temperature, providing real-time data that enables farmers to make more informed decisions. Utilizing IoT sensors for detailed soil analysis helps in generating customized fertilizer and crop recommendations and improves the overall agricultural efficiency [4,5].

Furthermore, investigations into the impact of organic fertilizers on soil health and crop productivity have shown their benefits in enhancing soil health and long-term fertility. These studies indicate that organic fertilizers improve the physical structure of the soil and encourage microbial activity, which in turn reduces the need for chemical inputs and helps to decrease soil acidification and degradation. This could help farmers by recommending suitable organic fertilizers based on specific soil conditions, thus supporting sustainable and environmentally friendly farming methods[6-8].

The development of sensor-based soil monitoring systems for precision agriculture has also revolutionized agriculture. Researchers have constructed real-time soil monitoring devices using IoT sensors and microcontrollers and have demonstrated how such systems can be integrated to optimize resource use and increase yields. The proposed system is built on this idea by focusing on creating affordable IoT-based systems that continuously monitor soil conditions and dynamically adapt recommendations in response to changing environmental patterns, with the ultimate aim of ensuring better agricultural results [9.10].

3. Proposed Methodology

The methodology includes sensors, Node MCU, and machine learning to optimize crop and fertilizer recommendations. Soil moisture and environmental parameters are measured by sensors and sent to a NodeMCU (ESP8266). It is processed using machine learning algorithms, and results, including NPK values, suitable crops, and fertilizer suggestions are displayed on a webpage.

3.1 Data Collection

The Moisture Sensor and DHT11 Sensor along with the microcontroller forms the core of sensing environmental and soil conditions, providing real-time data for optimizing agricultural techniques. The Moisture Sensor measures soil water content, offering important insights into moisture levels that aid in proper irrigation management and healthy crop growth. The DHT11 sensor captures environmental parameters such as temperature and humidity, which influence plant growth and soil health. The combination of these sensors provides a comprehensive view of both soil and environmental conditions, thus facilitating informed decision-making for precision farming and crop management. This data-driven approach is essential for optimizing resource usage, improving crop yields, and ensuring sustainable agricultural practices.

3.2 Data Transmission

Once data is collected from the sensors, it is sent to the NodeMCU (ESP8266), a microcontroller with integrated WiFi functionality. The NodeMCU performs light preprocessing, such as validating the data format and compressing it for efficient transmission. This processed data is then wirelessly transmitted to the server, which acts as an intermediary before the data is uploaded to the cloud, reducing the chances of data loss and corruption during communication. The NodeMCU ensures energy-efficient communication, saving system costs and proving beneficial for remote areas with limited power. Utilizing IoT devices at this stage also ensures real-time, uninterrupted communication between field sensors and the remote processing unit.

3.3 Processing and Analysis

After data reception by the cloud infrastructure, a preprocessing phase is implemented to mitigate noise and inconsistencies, thereby ensuring data integrity for subsequent analytical procedures. This preprocessing stage is necessary for maintaining the accuracy and reliability of the dataset, as any latent errors or discrepancies could potentially lead to errors. Within the cloud environment, the system employs a random forest algorithm to compute the Nitrogen (N), Phosphorus (P), and Potassium (K) values for the soil. This algorithm establishes correlations between moisture and temperature levels and predefined soil data repositories. This analytical step is paramount, given that NPK levels serve as fundamental indicators of soil health and nutrient equilibrium, directly impacting crop productivity and long-term sustainability. By accurately determining these nutrient concentrations, the system facilitates the evaluation of potential soil deficiencies in specific elements, which is essential for the formulation of appropriate agricultural interventions.

After calculating the NPK values, the system uses this information to predict which fertilizers will be the most suitable for replenishing depleted nutrients in the soil by the Euclidean distance algorithm. The system provides the farmer with exact fertilizer recommendations according to the deficiencies detected in the soil, making fertilizer application both efficient and environmentally friendly. Another advanced predictive models are used to recommend the best crop for the conditions of soil and climate using both historical and current environmental data.

3.4 Storage and Cloud Connectivity

The cloud platform serves as a centralized repository for sensor data and processed results, ensuring secure storage and providing remote access to users at any time. All incoming data received from the sensors is securely uploaded and stored on the cloud, allowing for easy retrieval and management. The scalability of the cloud infrastructure is particularly beneficial as it can accommodate large datasets, making it ideal for both real-time data processing and long-term historical trend analysis. This feature is especially advantageous in agricultural applications, as it allows for large-scale deployments across multiple farms without the need for significant on-site computational resources. This collaborative approach not only streamlines the process of data interpretation but also improves the overall effectiveness of agricultural practices by utilizing the expertise and insights of multiple parties.

3.5 Insights Visualization

The analyzed data is presented to farmers or agricultural professionals through this webpage which is user friendly, web-based, and easy to use. This webpage gives a clear, concise overview of important environmental parameters [1] such as current soil moisture levels and temperatures, humidity, and predicted NPK. Furthermore, the system presents actionable insights on the form of recommended fertilizers and suitable crops to be farmed based on the nutrient content of the soil. To add to this decision-making process, the system makes use of alert and notification capabilities that notify important conditions such as low moisture and extreme temperature deviations so that such conditions can be intervened upon appropriately. The dashboard's visual representation of data simplifies complex information, making it accessible even to users with limited technical expertise [2]. This intuitive interface ensures that farmers and agricultural professionals can easily interpret the data and take appropriate actions to optimize their farming practices, ultimately improving crop yields and sustainability

4. Hardware Description

4.1 System Overview

The system monitors soil and environmental conditions to improve the effectiveness and sustainability of agriculture. It includes an ESP8266 WiFi module combined with a DHTII sensor that gauges temperature and humidity, as well as a soil moisture sensor that evaluates the soil's water content. The data collected from these sensors is wirelessly sent to a cloud platform or application for immediate analysis and monitoring. This type of system aids farmers in making informed decisions, optimizing irrigation timing, and managing soils effectively. As a result, it can also offer suggestions for organic fertilizers to encourage sustainable agriculture and enhance crop yield.

4.2 Circuit Diagram and Components

The Circuit diagram of the Soil testing system with the recommendation of organic fertilizer is shown in Figure 1 as follows

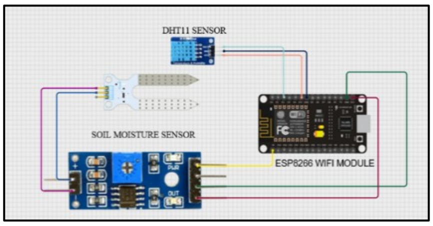

Figure 1. Circuit Diagram

The core components of the soil testing system are:

ESP8266 Wi-Fi Module: This microcontroller with integrated Wi-Fi enables data transmission. Its key pins include:

VCC: 3.3V power supply.

GND: Ground.

TX/RX: Serial data transmission and reception.

CHPD: Chip enable (HIGH for normal operation).

RST: Reset (LOW to reset).

GPIO0/GPIO2: General-purpose input/output pins, with GPIO0, also used for programming.

DHT11 Sensor: This compact digital sensor measures temperature (0-50°C) and humidity (20-90%). It utilizes a humidity-sensitive resistor, a temperature-sensitive thermistor, and an integrated chip to output digital signals through a one-wire interface.

Soil Moisture Sensor: This sensor measures the water content in the soil by determining its electrical resistance. Moist soil has lower resistance, while dry soil has higher resistance. It outputs analog or digital signals readable by a microcontroller, it is important for irrigation management in agriculture and smart farming. These hardware components, including the sensors and the ESP8266 as the core processor, are interconnected for data acquisition and processing.

4.3. Hardware Results

The Hardware results of the Soil testing system with recommendation of organic fertilizer is shown in Figure 2. In this setup, various hardware components such as the DHTII sensor and soil moisture sensor are linked to the Node MCU, which acts as the main processor. The DHTII sensor gauges temperature and humidity, while the soil moisture sensor evaluates the water content in the soil. These sensors consistently collect environmental data and transmit it to the Node MCU for additional processing. The Node MCU, a microcontroller with Wi-Fi capabilities built on the ESP8266, functions as the core unit, gathering real-time information from all connected sensors. It manages the incoming data and then forwards the results to the Arduino platform, where the captured values, including temperature, humidity, and soil moisture, are displayed for monitoring and analysis. To improve accessibility, the processed data is sent to a local server on a laptop through Wi-Fi.

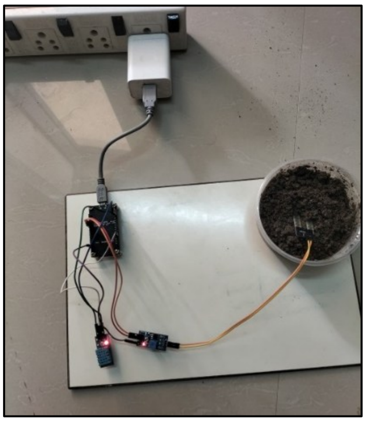

Figure 2. Hardware Model

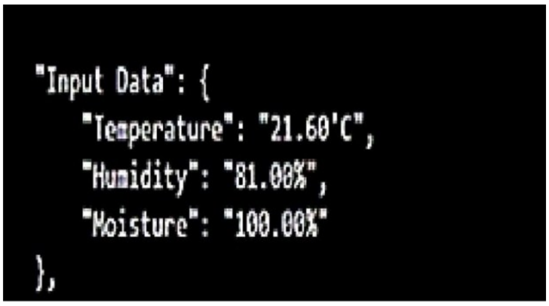

Figure 3. Hardware Output

This arrangement enables users to remotely view the sensor readings through a web-based interface,[4] allowing for real-time observation of soil conditions. This setup is particularly advantageous for smart agriculture practices, where continuous monitoring of environmental variables is essential for enhancing plant growth and irrigation management. The hardware output is illustrated in Figure 3.

4.4 Software Description

A. Random Forest Algorithm

The Random Forest algorithm is commonly used for classification and regression tasks in machine learning. It functions by creating many decision trees during the training process and merges their predictions. In this case, the Random Forest algorithm predicts the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in the soil, utilizing the given temperature, humidity, and moisture readings collected from the sensors. A spreadsheet in Excel with historical data forms the training data set.

B. Components in Random Forest

1. Decision tree

A decision tree shown in Figure 4 acts as the essential element of the Random Forest algorithm. It functions by splitting the data at each node based on a feature and a threshold that improves the separation between data points (utilizing impurity metrics that is Entropy).

- **Root Node:** The entire data set is carried.
- **Splitting Criteria:** Splits data based on a feature, for example, Moisture greater than 30
- **Leaf Nodes:** These are terminal nodes where the final predictions for the N, P, K values are made.

2. Data Subsets

During bootstrapping, random subsets of data are made of individual trees, promoting diversity in the forest. This randomness helps reduce overfitting, making the model more robust.

3. Dominant Feature

The algorithm splits data at a node by choosing the "dominant feature" that best divides the data. It assesses how effectively each feature lowers impurity in the data set.

4. Ensemble Learning

All predictions from the decision trees are combined. In regression, the Random Forest averages the predictions from all trees and gives an output on the levels of N, P, and K.

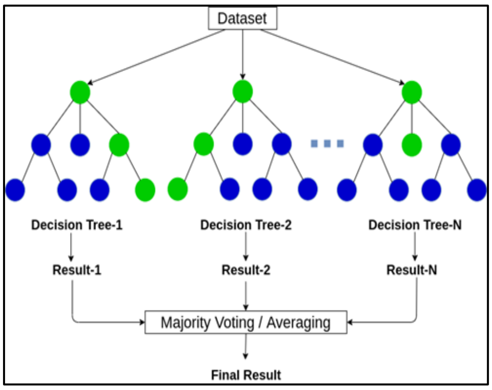

Figure 4. Sample Decision Tree [11]

C. Euclidean Distance Approach

The Euclidean distance method is a mathematical approach to measure how close or similar two data points are in a multidimensional space as shown in Figure 5. It is used to compare predicted soil nutrient levels, such as Nitrogen, Phosphorus, and Potassium, with optimal soil conditions in a database. The system then finds the best organic fertilizer and crop for the soil by identifying the closest match.

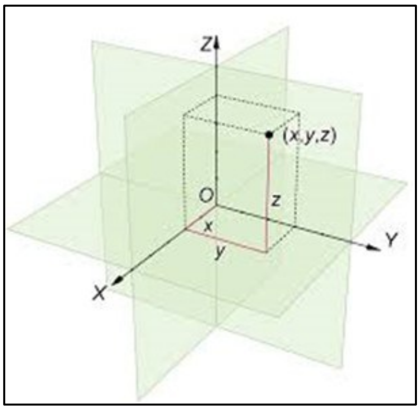

Figure 5. Euclidean Plane

Mathematical formula:

$$D = \surd(N1 - N2)^\wedge 2 + (P1 - P2^\wedge)2 + (K1 - K2)^\wedge 2$$

Where, $N1, P1, K1)$ are Input values for a given sample. $(N2, P2, K2)$ are Input values of another sample or query point. D is the Distance between two points in 3-dimensional space.

D. Webpage Designing

1. Role of Python

Python serves as the foundational technology for this initiative, facilitating the seamless integration of web application development, mathematical modeling, and data processing. The Pandas library is employed for the management and analysis of Excel-based data, ensuring the accurate reading, modification, and classification of Nitrogen (N), Phosphorus (P), and Potassium (K) values for fertilizers. The identification of optimal crop and fertilizer combinations based on user-input parameters relies on the NumPy library for mathematical computations, including the calculation of Euclidean distances. The Flask framework is used for the development of a dynamic web interface, enabling users to input data, execute concurrent processes, and visualize results through HTML templates [6]. Python's algorithmic capabilities contribute to informed decision-making by considering similarity scores and ranking the findings to recommend the most suitable fertilizer. Robustness is further enhanced through the incorporation of error-handling mechanisms, input validation protocols, and exception management for scenarios such as missing files or invalid data formats. Moreover, Python's flexible and scalable architecture provides versatility for future feature enhancements, including the integration of advanced analytics for forecasting and optimization, or sophisticated machine learning models. The extensive array of libraries and tools available within the Python ecosystem accelerates the development lifecycle, thereby rendering the research both user-accessible and efficacious for agribusiness decision support.

2. Role of HTML

In the developed system, HyperText Markup Language (HTML) served as a fundamental technology for the structural organization of the web interface. Through the implementation of forms, HTML defined the layout and content, thereby enabling users to input data about Nitrogen (N), Phosphorus (P), and Potassium (K) levels. Input fields and interactive buttons represented core HTML elements that facilitated a user-centric interface. The Flask framework provided seamless integration, enabling the dynamic presentation of results specifically, fertilizer recommendations and crop advisories that aa are contingent upon user-provided data. Furthermore, HTML exhibited compatibility with Cascading Style Sheets (CSS) and JavaScript. By establishing a connection between the backend Python logic and the frontend presentation layer, HTML ensured both user-friendliness and accessibility, consequently offering a cohesive user experience to the end-user.

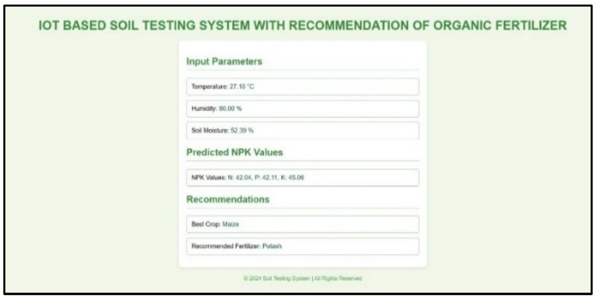

Figure 6. Webpage Output

The output in Figure 6 shows the IoT-powered soil testing system and, therefore, shows its ability to provide farmers with practical recommendations depending on the soil nutrient study. The system uses the input parameters to calculate the expected major nutrients Nitrogen (N), Phosphorus (P), and Potassium (K), and then offers valuable information. It suggests the best crop for the given soil conditions and helps to determine the amount of fertilization required to achieve optimum soil health, and checks if the current fertilizer levels are enough for farming.

5. Conclusion

The recommended IoT-powered soil analysis technique integrates sensor technology, artificial intelligence, and cloud connectivity to provide instantaneous data on soil health. The system efficiently collects data using soil moisture and environmental sensors, which is then analyzed by a Random Forest model to predict soil nutrient levels (NPK). The Euclidean distance method enhances these predictions even more to identify the most suitable organic fertilizers and crops, therefore ensuring precision in agricultural choice. The internet interface increases accessibility by allowing agricultural experts and farmers to remotely monitor soil quality and get practical advice. By reducing chemical dependence and improving soil health, this approach promotes sustainable agriculture approaches as well as optimizing the use of fertilizers. Its cost-effective construction and scalability make it suitable for widespread use, supporting government agricultural research, research institutions, and small-scale producers. This solution deals with major challenges in modern agriculture poor soil management, and lost resources by using machine learning and the Internet of Things. The application of real-time monitoring and predictive analytics ensures quick responses, therefore improving crop yields and maintaining environmental sustainability. Future initiatives might concentrate on enlarging the system by including more soil factors, enhancing prediction accuracy with deep learning models, and enabling mobile-based access for better usability in rural areas. This research highlights how smart farming solutions could revolutionize traditional farming methods, therefore guaranteeing higher yields and long-term soil preservation.

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