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IoT-Based Fuzzy Logic Controller for Smart Soil Health Monitoring: A Case Study of Semi-Arid Region of India †

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Abstract: The human population continues to grow, and specific efforts must be made in order to meet foreseeable food demands. In this paper, it is suggested that an IoT-based fuzzy control system has been used for smart soil monitoring systems. This study is based on the semi-arid regions of India. A fuzzy classifier is used to categorize the real-time data into three parameters, such as sodium, potassium, and calcium, based on the proposed model, which gets trained from a dataset and then chooses the optimal solution. The real-time data is collected from NPK sensors, which are suitable for sensing the content of nitrogen, phosphorus, and potassium in the territory, which helps in determining the fertility of the soil by facilitating the systematic assessment of the soil condition. With the aid of this system, a farmer would be able to monitor soil health in real time environment and also track the growth of their plants. Farmers will be able to enhance productivity while decreasing resource waste with the aid of an IoT-enabled fuzzy system. The experimental data has been collected from Mahoba district, Uttar Pradesh provinces in India, the results show that the suggested system is a more reliable and precise concept which is used for precision farming that will certainly enhance the overall production of the crop with better quality. These results obtained with the help of the proposed model system have been compared with the existing one with accuracy of the data that has been improved and well accepted.

Keywords: soil health; fuzzy logic controller; internet of things

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1. Introduction

A networked machine ecosystem is a fitting way to define the Internet of Things [1]. This technology has the potential to be widely used in agriculture for crop production improvement and soil health detection. Sensors are frequently employed to monitor soil parameters important for crop development [2]. Farmers receive several forms of data from the sensors, which are processed to improve agricultural productivity [3]. These sensors are managed by software applications designed expressly for this purpose. Sensors are used primarily for monitoring and control, security and warning, and diagnostics and analysis. It moves farming one step closer to self-sufficiency and independence from human involvement [4]. This study covers the IoT technology based on fuzzy logic that is used to monitor soil health in semi-arid locations. To make optimal judgments for precision agricultural activities, the research focuses on sensor technologies for real-time data collection and fuzzy logic controllers (FLC) [5] for approximate decision-making. This research looks at the use and uses of various sensors in the agricultural process. Their products are for sale in the marketplace. How these sensors are employed in different types of farms and how they benefit farmers, consumers, and the economy [6,7]. The materials and procedures used for the testing, the study area, a brief overview of the NPK sensor, fuzzy logic controller, and suggested technique for alert generation system are all included in Section 2 of the paper. Section 3 describes the modeling of various sensor parameters and fuzzy variables. Section 4 detailed the system's performance study and comparison with existing systems. Section 5 discussed the conclusion and improvement plan.

2. Materials and Methods

Dry areas with an aridity index of 0.20 to 0.50 are referred to as semiarid zones [8]. Due to historical land use, semi-arid soils commonly experience degradation, which leads to low levels of soil organic carbon (SOC) and poor structure. Human-caused erosion, salinity, and deterioration pose significant difficulties to semiarid soils. Our research is centered on the Mahoba district of Uttar Pradesh, India, which is classified as semi-arid. We put up numerous sensors in one area to collect datasets for the construction of fuzzy rules based on the proposed model. We use real-world inputs from a few selected sensors for testing. Figure 3 displays the recommended model's block diagram, which is made up of five parts. The first section is concerned with the design of NPK sensors, while the second part is concerned with converting the analog-to-digital signal (obtained from the NPK sensors). The third step is to create the fuzzy logic controller and inference rule based on the acquired dataset. The fourth step is to install the model in a cloud database, and the fifth step is to generate alarm messages.

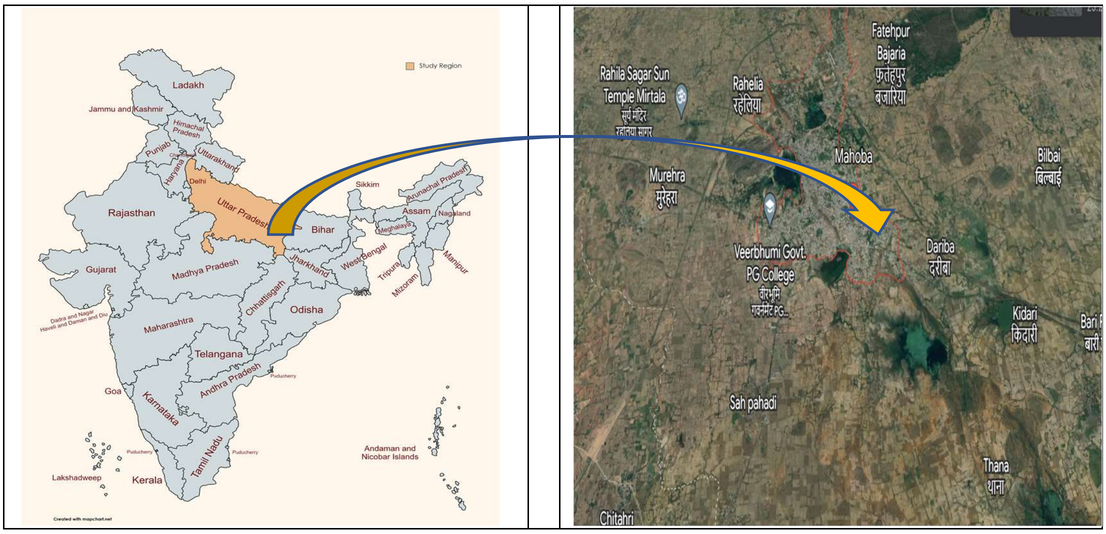

Figure 1. Study location of Mahoba district, Uttar Pradesh provinces in India (credit to Google map of geo tagged image).

2.1. NPK Sensor

The NPK sensor [9] setup includes four 10K resistors to detect the nutrients present in the soil while guarding against LED current overload: To determine the nutritional level of the soil solution, LEDs first transmit light into it. The colorimetric principle states that the chemical composition of the soil affects how much light will reflected from the solution. LDR absorbs these lights(using the concept photoconductivity), and the amount of light absorbed will record. The quantity of light absorption (A) in LDR will calculated using the Beer Lambert equation, in Equation (1).

$$A = K \times l \times c \quad (1)$$

where 'l' stands for the length of the light path, 'c' is the solution concentration, and 'K' stands for the molar absorptivity. Equation (2) states that the resistance level (RL) in a light-diffusing device (LDR) impacts how much light will reflect per unit of area (lux),and Equation (3) uses this information to compute the output voltage across an LDR.

$$R_L = \frac{500}{Lux} \quad (2)$$

$$V_o = I \times R_L \quad (3)$$

The voltage that results shows the nitrogen, phosphorus, and potassium concentrations in the test soil along with the data gathered by the sensor.

2.2. Fuzzy Logic Controller (FLC) for Soil Analysis

A mathematical concept called fuzzy logic deals with information that is imprecise. The Fuzzy logic, opposed to conventional binary logic, allows the representation of degrees of truth. A FLC is a decision-making system that interprets and reacts to input data using fuzzy logic concepts. Inference engine inferred the correspondence fuzzy value with the aid of pre-define fuzzy rules available in the knowledge base, and finally the defuzzification block converted the fuzzy output value to corresponding crisp value [10]. The fuzzy logic controller's block design is in Figure 2. It receives input data from an NPK sensor and fuzzified it to translate into desired language phrases. The inference engine determined the correspondence fuzzy value using pre-defined fuzzy rules from the knowledge base, which was subsequently translated into a corresponding crisp value by the defuzzification block [10].

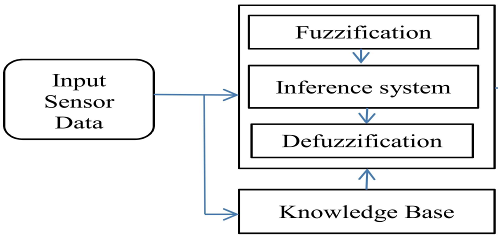

Figure 2. Proposed structure of FLC.

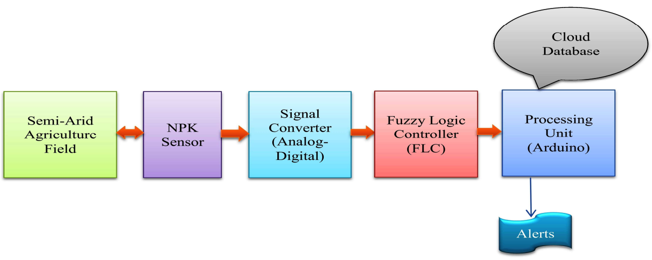

Figure 3. Schematic Flow of IoT Based Soil health Monitoring Module.

2.3. Alert Generation System Using IoT

The analog signals sensed by NPK sensor connected to an A-to-D converter [11]. That produced digital output linked to an Arduino device equipped with a WI-FI networking module to carry out more investigation into the soil's nutritional insufficiency. After receiving the LDR output voltage, the first step is to run a python program that employs a fuzzy inference technique to diagnose soil nutrient.

A system with software uploaded in accordance with the detected value, and it also alerts the field owners about the required fertilizer on a regular basis. The best fertilizer for the soil is selected in the second stage using the results of the fuzzy rule system. This process generates fertilizer in text form. The third stage of the program flow links the massage agent and transmits the message about fertilizer over the internet. The sensor value and fuzzy logic system response saved in the embedded program's link to the Google cloud database for later use. The modeling of fuzzy input parameters and its correspondence with fuzzy outputs is in Figure 4.

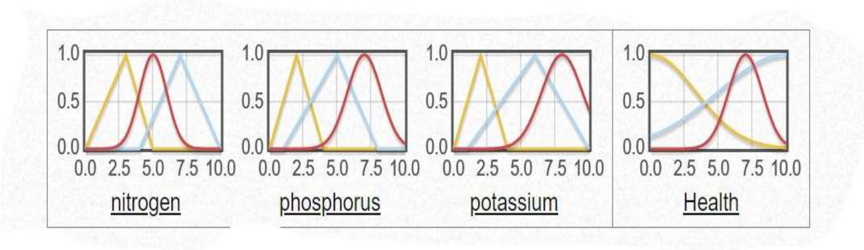

Figure 4. Modeling of the input and output linguistic parameters.

3. Modeling of Sensor and Fuzzy Parameters

The simulation program is used to transport data from the NPK sensor kit to the cloud server and asses performance factors such as throughput, end-to-end latency, and average jitter. It is accomplish by adjusting network density. Table 1 shows the fuzzy rules created by the fuzzy inference module and the associated output.

Table 1. Fuzzy inference rules generated by the system.

If N is Low and P is Low and K is Low **then** Health is Low
If N is High and P is Low and K is Low **then** Health is Medium
If N is Low and P is High and K is High **then** Health is High

The network protocols implemented in Python3.8, to assess network performance, several simulated scenarios ware developed. For the testing the model, we choosen ten nodes. Similar setups, including internet server 6, 7, 14, 19, 23, and 35 nodes used to analyze end-to-end throughput, latency, and jitter [12]. The implemented network performance is test in terms of scalability. The proposed system can deploy in real time to examine any type soil in semi arid lands. The hardware settings for the sensor nodes are in Table 2.

Table 2. Simulation Parameters.

Sl. No.	Parameters	Values
1	Time of Simulation	300 s
2	Area covered	1500 m × 1500 m
3	Frequency of channel	2.4 GHz
4	Path loss	Free space
5	Propagation Limit	−111 dBm
6	Transmission power	15 dBm

4. Results and Performance Analysis

The sensor's active mode determines how much energy it uses. The proposed system's sensor hasn't used in more than 24 h. Regular soil nutrient monitoring takes two to three days, or roughly 36 h, during the crop's growth. The crops grown in each agricultural area determine the relatively low sensing frequency and data transfer to the cloud. The proposed system outperformed the mentioned algorithms in the experiment using various machine learning algorithms, as shown in Figure 5 [13–20]. We adjusted the frequency of data transmission of numerous sensors to estimate energy conservation. Each sensor takes less than 0.14 mJ of energy to detect, analyse, and transmit data.

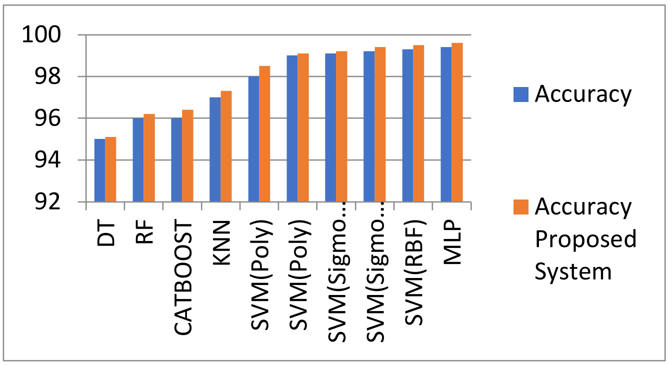

Figure 5. Comparative performance analysis of proposed system.

Throughput, or data transport rate through a network, is changed with network density. For analyzing throughput changes, the data transfer frequency is kept constant. Over a node density of 20, the throughput reaches saturation. The average end-to-end latency for every network density, is calculated by latency of the circuit (from the sensor to the server). The average latency increases as node density climbs, as a result, the shared network becoming increasingly congested during data transmission. The average jitter, which varies with node density, is 4 ms. The experimental results show that the suggested system can deploy in semi arid agricultural area for improving the soil helth and yields.The performance appears to be scalable, viable, and employable. Internet agents (as depicted in Figure 6) send out SMS about the appropriate fertilizer application depending on the present soil nutrient level in accordance with the system's output.

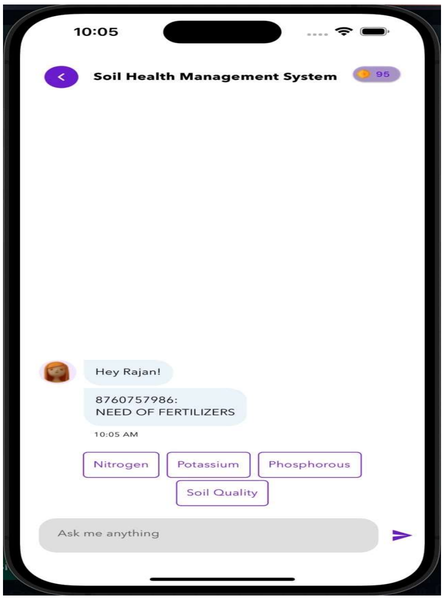

Figure 6. Alert Message recived by the land owner.

5. Conclusions

It is challenging to routinely evaluate soil nutrients in agricultural fields due to conventional testing mehods. The suggested system notifies the farmer by SMS of the absence of critical soil nutrients, specifically nitrogen, phosphorus, and potassium. It does this by the system's integrated NPK sensor and fuzzy-system. The outcomes of the proposed model performed is to understand better how the built IoT system works and to describe its intended purpose. The experiment shows that the suggested system is accurate, low-cost, and intelligent Internet of Things (IoT) system that instantly alerts the farmer by SMS about the fertilizer that needs to apply at the right moment. This system might be a helpful tool for farmers in the agricultural industry.

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