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An automated low cost IoT based Fertilizer Intimation System for smart agriculture

Lavanya G[a], Rani C[b], Ganeshkumar P[c,*]

[a] Department of Information Technology, Sri Krishna College of Technology, Coimbatore, Tamil Nadu, India
[b] Department of Computer Science and Engineering, Government College of Engineering, Salem, Tamil Nadu, India
[c] Department of Information Technology, Anna University Regional Campus Coimbatore, Tamil Nadu, India

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A B S T R A C T

This paper presents an Internet of Things (IoT) based system by designing a novel Nitrogen-Phosphorus-Potassium (NPK) sensor with Light Dependent Resistor (LDR) and Light Emitting Diodes (LED). The principle of colorimetric is used to monitor and analyze the nutrients present in the soil. The data sensed by the designed NPK sensor from the selected agricultural fields are sent to Google cloud database to support fast retrieval of data. The concept of fuzzy logic is applied to detect the deficiency of nutrients from the sensed data. The crisp value of each sensed data is discriminated into five fuzzy values namely very low, low, medium, high and very high during fuzzification. A set of If-then rules are framed based on individual chemical solutions of Nitrogen (N), Phosphorous (P) and Potassium (K). Mamdani inference procedure is used to derive the conclusion about the deficiency of N, P and K available in soil chosen for testing and accordingly an alert message is sent to the farmer about the quantity of fertilizer to be used at regular intervals. The proposed hardware prototype and the software embedded in the microcontroller are developed in Raspberry pi 3 using Python. The developed model is tested in three different soil samples like red soil, mountain soil and desert soil. It is observed that the developed system results in linear variation with respect to the concentration of the soil solution. A sensor network scenario is created using Qualnet simulator to analyze the performance of designed NPK sensor in terms of throughput, end to end delay and jitter. From the different variety of experiments conducted, it is noticed that the developed IoT system is found to be helpful to the farmers for high yielding of crops.

1. Introduction

Agriculture [1] is the major occupation that contributes to overcoming food scarcity. It will be successful only when the farmers are able to produce high yield in their cultivation. Lower the yield of cultivation in agricultural field [2] effects the revenue generation of the developing country. One of the major reasons for low yield is the improper use of fertilizers by the farmers. The fertilizers can be added at appropriate quantity during the lack of nutrients in the soil. Hence, testing the soil for the nutrients available for the plant growth is inevitable before adding fertilizer. Soil testing is widely conducted to estimate the availability of nutrients present in the soil for plant growth. Determination of fertilizer recommendation [3] for effective plant growth is the main outcome of soil testing. But soil testing is rarely done by the farmers because of its complex laboratory procedure [4]. In general soil testing for the nutrients [45] is carried out manually in commercial laboratories that cannot facilitate the farmers because of more time consumption and high cost.

Few impacts of soil testing are to avoid the excessive use of fertilizer and minimize the fertilizer expenditure. Also the ability of farmers to protect the fertility of soil by knowing the current condition of the soil is improved [24]. Further it helps to avoid soil degradation. Generally, Soil testing [5] is done for soil pH, macronutrients like nitrogen, potassium and phosphorus and micronutrients test for another mineral like zinc, calcium, copper, lead, etc., in a separate method. Different Instruments of soil testing are atomic absorption spectrophotometers, Inductively Coupled Plasma Spectrometers (ICPs), Lachat Flow Injection Analyzer, colorimeters and general laboratory equipment. Each instrument uses a principle of chemical analysis, electrolysis, spectroscopy, colorimetric, etc.

* Corresponding author.
E-mail addresses: g.lavanya@skct.edu.in (L. G), rani23508@gmail.com (R. C), ganesh23508@gmail.com (G. P).

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Soil test for macronutrients is carried out separately for nitrogen, phosphorus and potassium [44], which is time-consuming and not economic for the farmers. Ezeokonkwo [6] performed a manual experiment with different proportion of NPK fertilizers added at different levels (low, adequate and excess) of nutrient soil to analyze the engineering properties of soil. Even though the experiment inform the farmer about how the use of the excess of fertilizer affect the soil properties like unit weight, water content, tensile strength, permeability and so on it is a laborious process.

Developed countries encourage their farmers to digitize the traditional way of doing things in a smarter way with the support from the Internet of Things (IoT) [25,28–33]. IoT is the concept of networking the physical objects with the ability to transfer the data from sensors [26] over the internet. The significant reason for IoT appearance [27] in today's world is to automate a system and provide a remote control and monitoring over the system through internet. This paper discusses the development of an IoT based system with the help of a novel NPK sensor and fuzzy algorithm to facilitate the farmers about the awareness of soil nutrients deficiency and appropriate fertilizer to be added to the fields at right time.

The key contributions of the proposed research are:

(i) Design of novel NPK sensor by incorporating the colorimetric principle using Light Dependent Resistor (LDR) and Light Emitting Diodes (LEDs)
(ii) Integration of NPK sensor with the software embedded in microcontroller unit for analyzing the sensed value
(iii) Development of a fuzzy rule-based system to analyze the sensed value to decide upon the proportions of N, P and K in the soil at edge level.
(iv) Internet-based user-friendly and automated intimation system at regular intervals of time to the farmers' electronics gadgets.

This paper comprises of review of related work in Section 2, proposed system design described in Section 3, IoT layered protocols implemented in the system described in Section 4, simulation of extended system as wireless sensor network is explained in Section 5, hardware implementation and test results in Section 6 and the conclusion in Section 7.

2. Related work

This section enlightens with the allusions related to the progress of our solution stage by stage with appropriate principle involved in design of sensor and analysis of soil nutrients.

One of the accurate methods to detect the chemicals in the solution is using the colorimetric principle. Doyle et al. [7] experimented the presence of carbon and nitrogen in soil extract in the laboratory. Yong he et al. [8], proposed a colorimetric-based analysis to detect the urinalysis dipsticks in urine samples. Henrikenson and Olsen [9] determine the occurrence of nitrite and nitrate in water and soil extract using colorimetric principle. Regalado and Cruz [10] analyzed soil pH and nutrients level especially the presence of nitrogen, phosphorus and potassium in the soil using the colorimetrical principle with the help of a color sensor. However, the system failed to intimate the farmers about the kind of fertilizer to be used for a particular nutrient. Deepa et al. [11], focused on detection of NPK nutrients using colorimetric principle with the help of fiber optic channel for light transmission. Ben-dor and Banin [3] proposed the infrared analysis to evaluate the soil properties. However, it involves manual testing that becomes a laborious and expensive task for the farmers. To the best of our knowledge it is found that even though researchers performed experiments for testing the nutrient level in the soil, the majority of the farmers are unable to know the results and the required solution during the cultivation. Hence in this paper, we propose a solution to conduct the soil test for nutrients at the agricultural land using colorimetric principle, by designing a novel sensor.

Many types of sensors were designed using the colorimetric principle for various applications to perform the chemical properties. Dissanayake et al. [12] developed an optical sensor to detect fluoride and pH level in order to analyze the water quality using colorimetric principle. Chen et al. [13], proposed a colorimetric-based barcode sensor for food quality and spoilage based on a disposable optical sensor. Kim et al. [14], proposed a portable array reader to detect the color changes of the colorimetric strip responding to various hazardous gases through the CMOS image sensor. Cheng and Meng [15] proposed an optical sensor based on colorimetric principle using the sensing film of a-naptholphthein as PolyIBM layer. Kodir et al. [16], proposed a pesticide colorimetric sensor using L-Cystene modified silver nano-particles. All the above sensor design work is based on the components that emit color lights and reflection of the same with different intensity. These devices are high-cost CMOS devices. Hence in this paper, we propose a novel sensor design using the colorimetric principle to determine the level of N, P and K in the soil with color LEDs and a light absorber LDR.

In general, the analysis of nutrient deficiency is examined at the measurement side using a microprocessor unit. A suitable logical system is required to analyze the soil nutrient level from the results of the sensor at the edge level. Since the sensor data acquired from NPK sensor is vague and uncertain, it becomes difficult to make decision on the soil nutrients level. Many studies reported that the problems with uncertain data in any field of engineering can be solved by a fuzzy rule-based system (FRBS) to ensure accurate decision. Owing to the success of FRBS for decision making in vague environment, the author turned their attention to refer papers dealing with the implementation of fuzzy basic for edge analysis of sensor data.

Zakarian [17] proposed a fuzzy logic and approximate rule-based reasoning approach for the analysis of process model to represent uncertain process variables. Dutu et al. [18], performed an analysis on fuzzy rule-based systems by generating fuzzy rules from numerical data. The fuzzy rule-based system greatly improves the accuracy for growing complex real-world problems. According to Feng [19], the fuzzy system can be employed in the sophisticated intelligent control system and identification of uncertain parameters.

Zulfikar et al. [20] implemented the Mamdani fuzzy system and found that the model has 91.4% accuracy to make suitable decision on an uncertain situation. Hong and Lee [21] proposed a learning method that reduces and human effort in the development of a fuzzy expert system for deriving the membership functions and fuzzy if-then rules. GaneshKumar et al. [22], proposed an improved technique to extract a fuzzy rule set and tune the membership function using enhanced particle swam optimization. Fuzzy inference system is also employed in interference reduction [23] of cognitive radio networks. In this paper, we propose a fuzzy rule-based analysis to identify the soil nutrients. It is implemented using Mamdani inference procedure that has NPK sensor data as input with three nutrients level (N,P and K) as output.

3. Proposed IoT system for fertilizer intimation

Due to the limitations prevailing in the conventional way of testing the soil in the laboratory and then reporting to the farmers to start cultivating the land, this paper suggests an IoT system that monitors the nutrients present in the soil and then alert the farmer

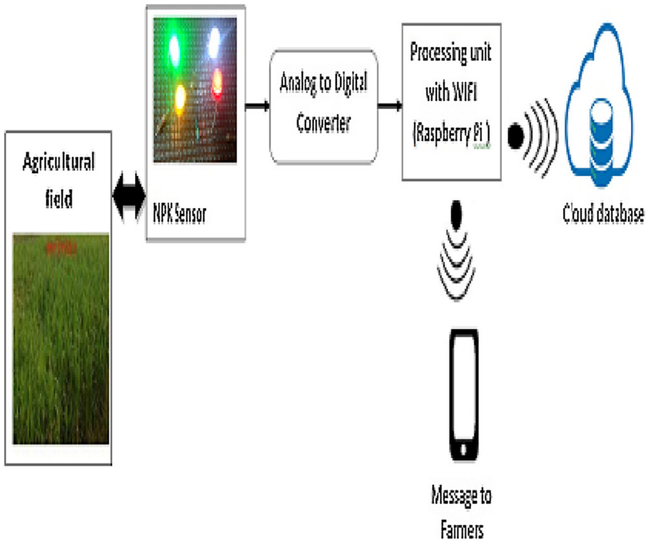

Fig. 1. Block diagram of proposed IoT based Fertilizer Intimation System.

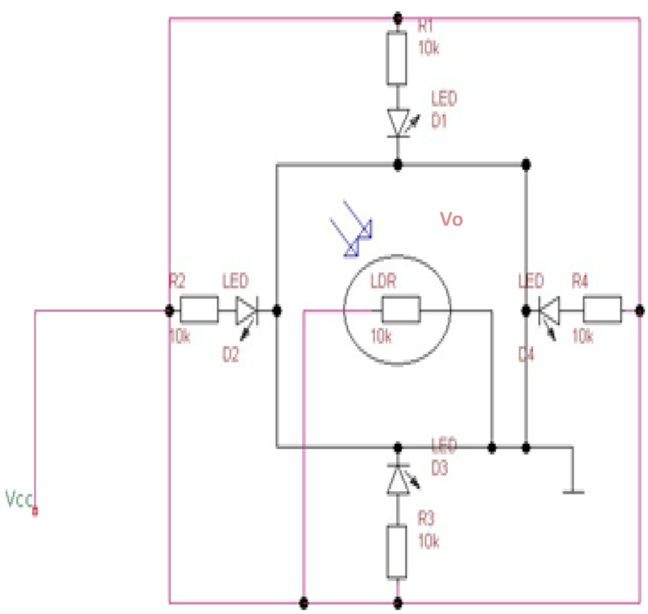

Fig. 2. Circuit diagram of NPK Sensor.

in their respective farm field about the quantity of fertilizer to be used during cultivation of land. Fig. 1 shows the proposed IoT system that senses the soil about the quantity of the nutrients present in the soil. The development of the proposed IoT system can be illustrated under three phases viz., 1. Design of NPK sensor, 2. Analysis of soil nutrient using Fuzzy Logic 3. SMS alert system to the farmer.

3.1. Design of NPK sensor

The proposed NPK sensor is designed using four different color Light Emitting Diodes (LED), a Light Dependent Resistor (LDR) and four Resistors. Fig. 2 shows the connection of components that make the NPK sensor. In Fig. 2, V_{cc} is the input voltage (V), R_1, R_2, R_3 and R_4 are resistors of 10 KΩ to resist the current overflow in LEDs, V_o is the output voltage across the LDR in V. The circuit design given in Fig. 2 works as follows to sense the nutrients present in the soil as listed below:

At first, LEDs emit the light on the soil solution chosen for testing the nutrients level. Based on the colorimetric principle [7], light

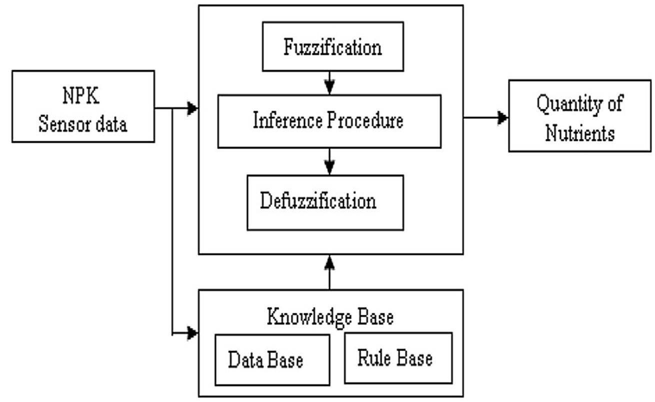

Fig. 3. Construction of Fuzzy System for Soil Nutrient Analysis.

reflected from the soil solution depends on the chemical concentration present in the soil. Reflected light from the soil solution is absorbed by LDR as per the photoconductivity principle [12], and is recorded depending on the amount of light absorbed. As per Beer-Lambert law, the amount of light absorption (A) in LDR is given in Eq. (1).

$$A = K \times l \times c \tag{1}$$

where 'K' is the molar absorptivity, 'l' is the path length of the light and 'c' is the concentration of the solution. The amount of light reflected per unit area (Lux) varies with the resistance level (R_L) in LDR according to the Eq. (2) and it is used to calculate the output voltage (V_o) across LDR as per Eq. (3)

$$R_L = \frac{500}{Lux} \tag{2}$$

$$V_o = I \times R_L \tag{3}$$

This output voltage is the data sensed by the proposed NPK sensor that gives the value of Nitrogen, Phosphorous, and Potassium available in the soil selected for testing.

3.2. Analysis of soil nutrients

Once the data is sensed by the designed NPK sensor, then it is analyzed to find the level of nitrogen, phosphorous and potassium content in the soil. In general, there are two ways of analyzing the sensor data, (i) Fog Computing and (ii) Edge Computing. The former analyzes the sensed data using a processor that makes contact with the physical world, while the latter analyzes the sensor data over the internet at a centralized smaller edge server called as cloudlet [29]. Since the data sensed by the proposed NPK sensor is the voltage based on the chemicals present in the soil solution, the analysis is performed at the edge level to determine the level of N, P and K in the soil.

Analyzing the NPK sensor data result in making the decision about the quantity of fertilizer to be used before cultivation. This is a complex task since the sensed data from soil solution are vague with ambiguous boundaries among the values. To address the issue, the concept of fuzzy logic is used to arrive at the definite conclusion regarding the amount of fertilizer. The various steps in constructing a fuzzy logic based sensor data analysis are shown in Fig. 3

Fuzzification is the task of partitioning the input variable and assigning the linguistic label for each partition. In general, partitioning is carried out based on the range of the sensed data value with little overlap in the range of each linguistic label. Table 1 shows the range of linguistic values assigned for 50 g of red soil dissolved in 100 ml of water. In this work, the crisp value of the NPK sen-

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Table 1
Fuzzification.

NPK Sensor Value (Crisp Value)	Fuzzy Range	Linguistics
610–620	0–0.1	Very low
620–625	0.1–0.3	Low
625–630	0.3–0.5	Medium
630–635	0.5–0.8	High
635–640	0.8–1	Very High

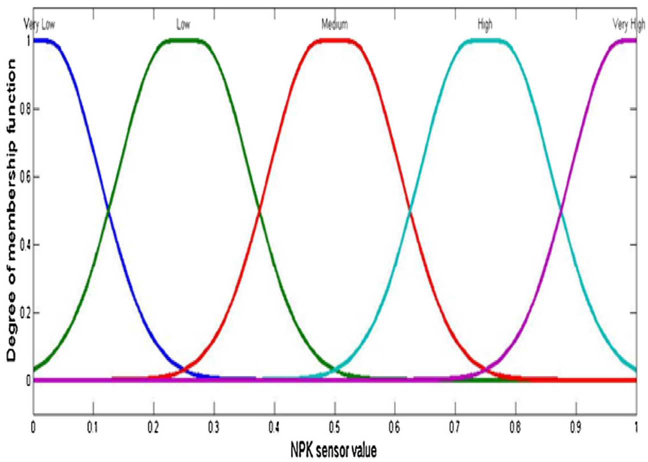

Fig. 4. Membership function of NPK sensor value.

sor data is divided into five linguistic labels namely very low, low, medium, high and very high.

The range of NPK sensor value is computed based on the sensed value from the chemical mixed soil solution that consists of the major components of nitrogen, phosphorus and potassium respectively. The sensed range also varies with type of soil and concentration of the soil solution as experimented and results are discussed in Section 6.1.

For the reason of the concise notation and smooth characteristics, the Gaussian function is selected as the membership function $\mu_{A_i}(x)$ for the input (NPK sensor value) to represent the linguistic term A_i as given in Eq. (4)

$$\mu_{A_i}(x) = e^{-\frac{(c_i - x)^2}{2K_i^2}} \tag{4}$$

Where c_i and K_i are the centre and width of the fuzzy set of A_i respectively. The width K_i is fixed based on the fuzzy range as given in Table 1.The fuzzy portion of the input variable (NPK sensor value) of the proposed system is shown in Fig. 4.

The three output variables of the proposed system that make definite decision are the level of nitrogen, phosphorus and potassium present in the soil solution. They are represented as three linguistic values low, medium and high. Although the partitioning and the type of membership function are same for each output variable (N, P and K) as shown in Fig. 5(a)–(c), they are different in terms of respective nutrients level in the soil.

Collection of conditional statements in the form of "if-then" statements is generated intuitively to form the rule based system. They are triggered together for a given input value to get the output decision about the level of nitrogen, phosphorus and potassium. Table 2 shows the rules framed for this work.

Mamdani Inference System is used in this work, that performs the task of triggering all the rules simultaneously to determine the level of N, P and K present in the soil solution. The NPK sensor value is mapped against each linguistic label to get the fuzzified value. The fuzzy implication applied to get the decision is explained as rules defined in Table 2. It can be written as a conditional statement as

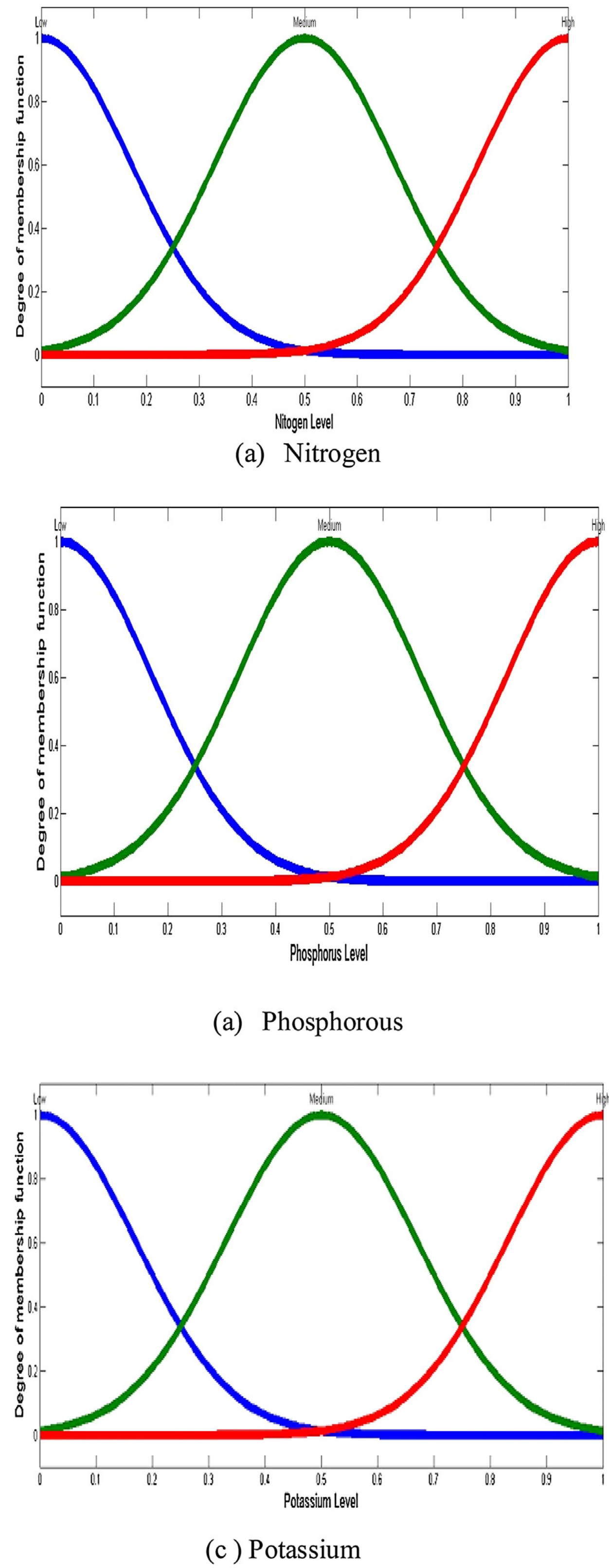

Fig. 5. Membership function of Output variables.

in Eq. (5)

$$\begin{aligned} &If\ (NPK\_sensor\_value) \rightarrow \textbf{Very Low} \Rightarrow (N \rightarrow \textbf{Low}) \\ &AND\quad (P \rightarrow \textbf{Low})\quad AND\quad (K \rightarrow \textbf{Low}) \end{aligned} \tag{5}$$

Table 2
Collection of If-Then Rules.

Rule	Range	NPK sensor Input	Nitrogen Level	Phosphorus Level	Potassium Level
1	0–0.1	Very low	Low	Low	Low
2	0.1–0.3	Low	Medium	Low	Low
3	0.3–0.5	Medium	Medium	Medium	Low
4	0.5–0.8	High	High	High	Medium
5	0.8–1	Very high	High	High	High

This rule is triggered in the edge analysis when the fuzzified value of the NPK sensor in the range of 0–0.1 (as per Table 1) and implies that the nitrogen is low, phosphorus is low and potassium is low. Similarly, based on the sensed value the decision is taken through edge computing using a microcontroller to provide the level of major nutrients in the soil.

Centre of Gravity (CoG) as given in Eq. (6) is applied over the aggregated response of rule base that converts the fuzzy value into crisp value to mention the level of N, P and K

$$CoG = \frac{\int_a^b \mu_A(x)xdx}{\int_a^b \mu_A(x)dx} \tag{6}$$

3.3. IoT based SMS alert generation

The proposed work aims to facilitate the farmers with the intimation of the appropriate fertilizer to be added to the soil at right time by an automated IoT system. This section describes the connectivity of the developed IoT system for generating SMS alerts.

The designed NPK sensor is connected to the processing unit to pursue the edge level analysis of sensed data and the respective fertilizer information is sent through the internet. The analog value sensed by the NPK sensor is connected to Analog to Digital Converter (ADC) - MCP3008. Fig. 6 shows the connection diagram of NPK sensor with the Raspberry pi through ADC. The digital output of ADC is connected to raspberry pi with WI-FI connectivity for further analysis of the lack of nutrients content present in the soil. On receiving the output voltage of LDR as the reflection of the light resistance value in the sensor, the first method of python program embedded in the processor of Raspberry pi that employs the above mentioned fuzzy inference system is executed to identify the deficiency of soil nutrients. A system is uploaded with the software that also sends a Short Message Service (SMS) to the field owners about the required fertilizer at regular intervals of time respective to the sensed value.

Based on the output of the fuzzy rule system embedded in the Raspberry pi, the second method is executed to determine the appropriate fertilizer to be used for the soil. The method provides a text output of either urea or potash or ammonium phosphate or NPK fertilizer (for example Big-3). The third method in the flow of the program is executed to link the SMS agent and send the fertilizer message through the internet. The other part of the embedded program is to connect to the Google cloud database and push the sensor value and the response of the fuzzy logic system for future analysis.

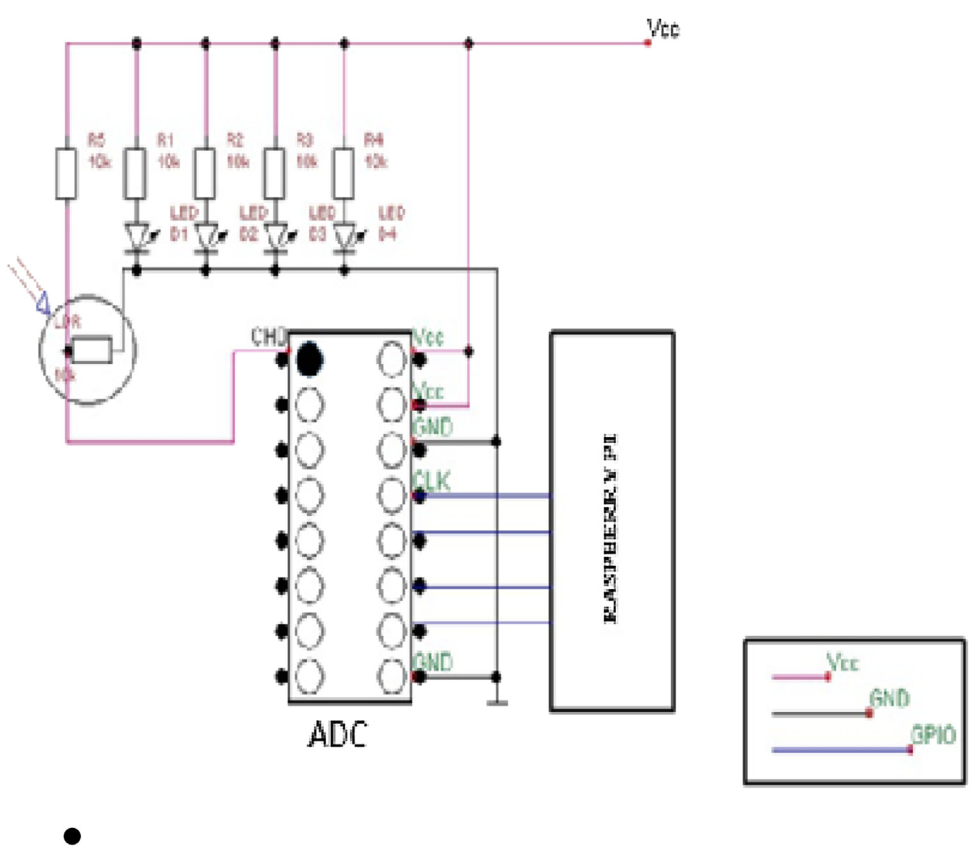

Fig. 6. Connection diagram for SMS alert generation.

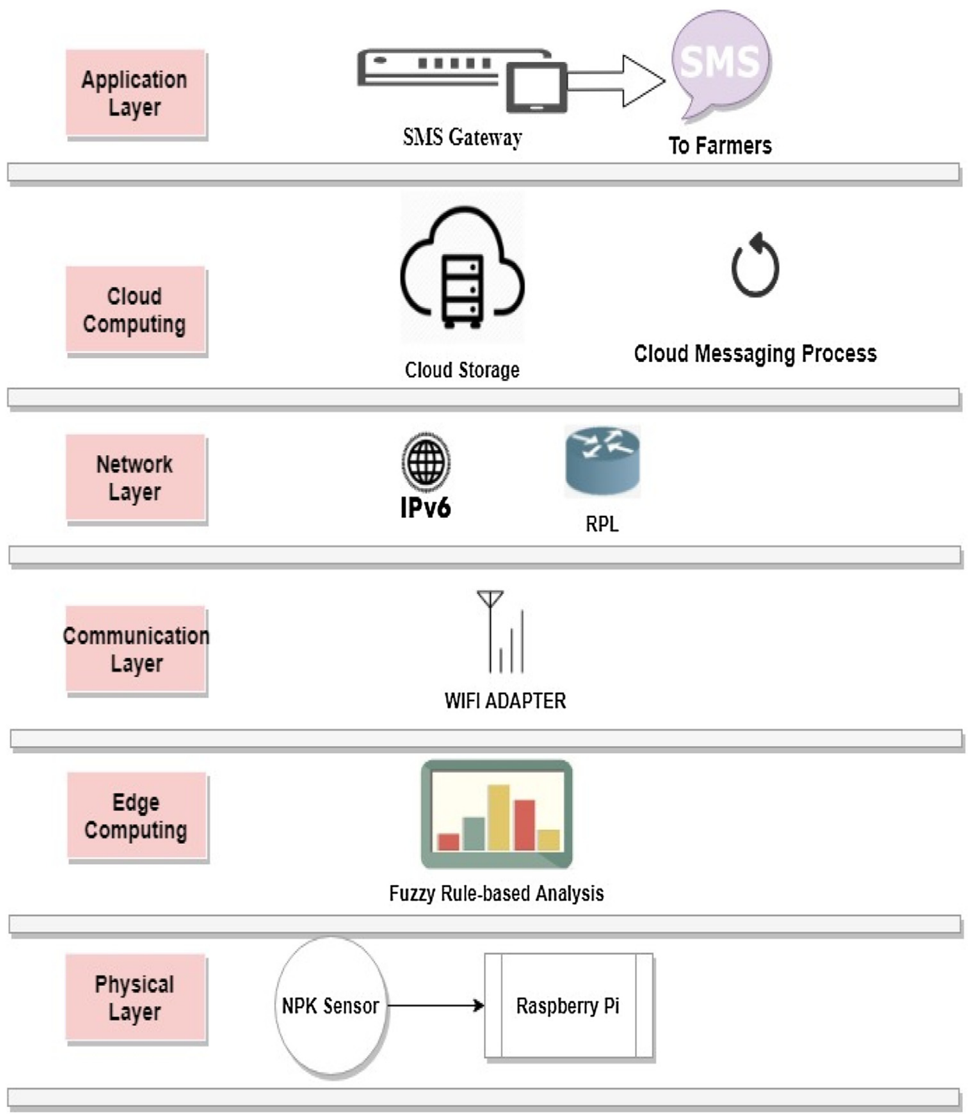

Fig. 7. IoT Functional Architecture Design.

4. IoT protocol stack

Rapid growth in Information & Communication Technology (ICT) [42,43] has enabled the IoT to integrate the physical objects with a unique identifier in order to transmit data over the internet without involving human interactions. By automating the physical objects using ICT, controlling and monitoring the same can be performed without much human interaction. Any physical object becomes a smart object by integrating the desired sensor and processing unit over the internet.

Development of an IoT system involves the design of hardware, software and communication interface. The proposed IoT system is shown in Fig. 7. This proposed IoT system can be extended and implemented in an agricultural land to provide the necessary information about the fertilizer to the farmers. Multiple sensor units transmit the information of respective NPK sensor to the cloud database through internet after the edge analysis based on fuzzy logic in Raspberry pi.

The physical layer consists of NPK sensor and microcontroller unit to process the sensed value and to identify the deficiency of soil nutrients. This layer uses IEEE 802.11 ah for providing a low energy wireless medium access protocol (i.e.) low energy WIFI. It is employed in data link layer because it possess qualities such as low energy, less overhead, power friendly communication, better synchronization short MAC frame of 30 bytes, NULL data packet as acknowledgement frame and increase sleep time.

As the proposed system consumes less power and RPL basically works based on one route from every leaf node to the root, it is used in the network layer. It builds a Destination Oriented Directed Acyclic Graph (DODAG) based on sending an advertisement frame from the root node. The advertisement frame DODAG Information Object (DIO) is initially broadcasted to the network and whole DODAG is formulated according to root from each leaf node is discovered to send data to root. When a NPK sensor node is ready to transmit its data to cloud database and then it sends a Destination Advertisement Object (DAO). After the DAO Acknowledgment, then the data is transmitted to destination via the identified route. If a new sensor is added to join the network, it sends a DODAG Information Solicitation (DIS) request to join the network and root will reply through DAO Acknowledgment to confirm the joining of the node and discovered root.

In order to develop as a low power Wireless Personal Area Network, IPV 6 is used in the proposed system. Network encapsulation layer encapsulates IPV6 long header in small packets which is less than 128 bytes. Fragmentation header is used to split the IPV6 header to 128 byte long fragments. Since the data from the

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NPK sensor node is transferred to the cloud database, the message queuing protocol employed in the proposed system is Constrained Application Protocol (CoAP). It provides a lightweight RESTful (Representation State Transfer) Interface. CoAP enables low power sensors to use RESTful services to meet the power constraints and support over User Datagram Protocol (UDP). The confirmable message transfer system in CoAP is used to acknowledge the NPK sensor node from the Google cloud database. Cloud messaging service is developed to analyze the data received in the cloud storage and generate the respective nutrients deficiency and appropriate fertilizer message.

In the application layer, the SMS gateway is linked to receive the generated Message and forward to the farmers. Another optional way introduced in the application is to use Hyper Text Transfer Protocol to load the sensor data into Cloud server for future analytics of the soil nutrients.

5. Implementation of cloud database

In the proposed system, the sensed data is transferred to the Google cloud database to store the data for future analysis and also to provide a monitoring of soil nutrients by the National or State level agriculture officials. The steps for transferring the sensor data to Google cloud database are as follows:

Step 1: Create a project wizard in the Google developer console to automatically turn on the Google Application Program Interface (API).

Step 2: Create an OAuth2.0 client ID in the Google cloud platform console

Step 3: Include OAuth client ID in the developer console and type the product name and save it

Step 4: Create a credential for OAuth client ID and choose others in the application type and enter as “Google sheet API Quickstart” to create the credential and JavaScript Object Notation (JSON) file with the API key

Step 5: Download the JSON file for the appropriate client ID.

Step 6: Store the JSON in the working directory of the embedded project

Step 7: Create a Google database to load the data and share the database with the client email ID generated in the downloaded JSON file.

Consequently, the data is loaded into Google cloud database that can be saved as CSV file for further data analysis

6. Simulation result and discussions

This section discusses the results of designed NPK hardware sensor node and the simulation of the proposed system in Qualnet 4.0 simulator.

6.1. Hardware testing

Single node consisting of NPK sensor connected with Raspberry pi 3 board is designed as shown in Fig. 6. The developed NPK sensor is examined under two parameters viz voltage and concentration of soil. These two tests are conducted for three different types of soil namely red soil, mountain soil and desert soil.

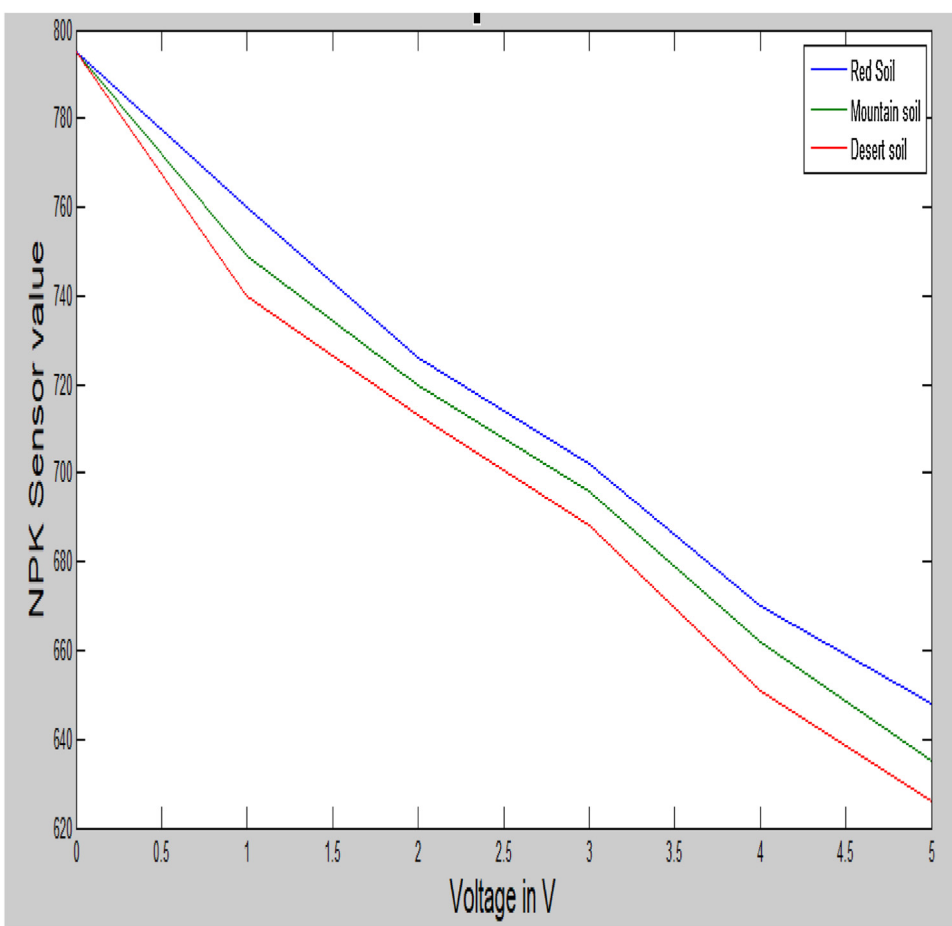


Fig. 8. Output of NPK sensor with voltage levels.

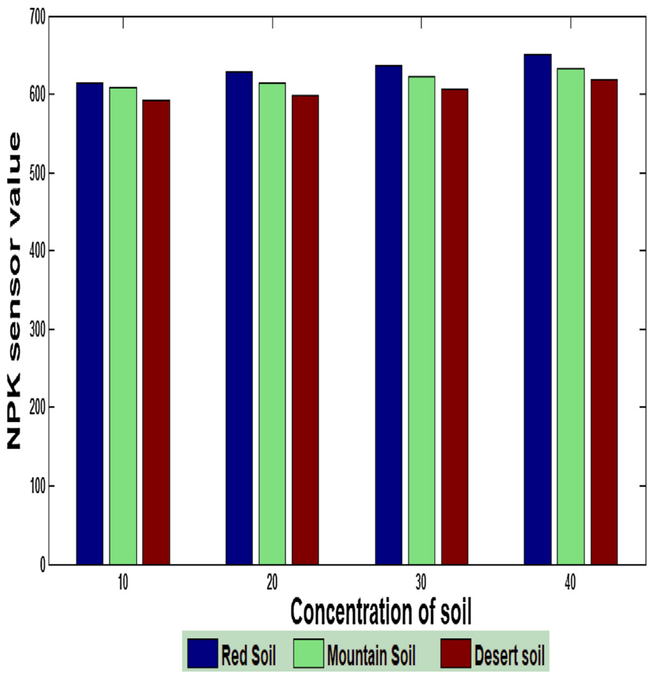


Fig. 9. NPK sensor response based on density of soil solution.

First, the NPK sensor is tested by varying the voltage of LEDs in the sensor. A sample soil solution in the ratio of 50 g of soil with 100 ml of water is taken for conducting the test. This test is carried out to prove that the sensor works according to Eqs. (2) and (3) mentioned in Section 3.1 By varying the voltage level from 0 V to 5 V to the NPK sensor, the output of the sensor also varies. It is shown in Fig. 8 that the value of the sensor is declining proportionately as the voltage increases. This confirms that the designed NPK sensor performs its duty according to Beer-Lambert law.

Second, the NPK sensor is tested for nutrients level by varying the concentration of soil solution in order to prove the implementation of colorimetric principle.

This test is conducted by providing an input of 5 V dc for three different variety of soil namely, red soil, mountain soil and desert soil. Fig. 9 shows the NPK sensor value for the different type of soil with respect to the concentration of the soil solution.

It is observed that the sensor value varies for 3 different soil and is proportionately increasing with respect to the concentration of soil with an equal measure of water. The range of NPK sensor can be set based on the type of soil and their standard properties of the soil with the well defined concentration of the soil solution.

It is advised that the designed sensor can be covered with an opaque material to ensure good response without the interference of the external light source. The developed hardware NPK sensor value for a soil sample remains constant in all instance for a period of 24 h. This is because the soil nutrients level does not vary with respect to time. But it will vary as the crops gain nutrients from the soil during their growth.

So the soil nutrients testing could be set to regular interval of time (weekly once or monthly once) in the software based on the type of soil and the crop planted in the field. It is recommended that the automated sensing can be set as the discrete measurement such that the sensor unit remains idle other than measurement. Since the components used in sensor design cost low, the cost of the developed system is less when compared to the manual soil testing in laboratory

Fig. 10 shows the graphical view of simulated rules of the fuzzy system. The last row in the graph shows the inference from the sensor value. Fig. 10 (a) shows Rule 1 with NPK sensor data as soil nutrients level being very low indicates the soil is deficient in nitrogen, phosphorus and potassium. The range of sensor value is in Table 2. From the output of Rule 2 shown in Fig. 10 (b), the low range of sensor value indicates that nitrogen is at an adequate and deficiency exists in phosphorus and potassium

In rule 3, the medium range of sensor value indicates the adequate level of nitrogen and phosphorus with potassium deficiency as shown in Fig. 10 (c). The high sensor value in rule 4 indicates the high level of nitrogen and phosphorus with an adequate quantity of potassium as shown in Fig. 10 (d). Rule 5 shown in Fig. 9(e) represents the excess quantity of nitrogen, phosphorous and potassium in case of the very high value measured from NPK sensor.

The variation and decision on the level of nutrients present in the soil are realized and implemented in the fuzzy inference system embedded within the microcontroller. The simulated result of the designed fuzzy system is shown in Fig. 11(a–c). It is observed that for all fuzzified values of the NPK sensor value, there exist a fuzzified value of nitrogen, phosphorus and potassium as shown in Fig. 10 (a–e).

Fig. 11(a) shows the presence of nitrogen in the soil solution for various NPK sensor value sensed from the sample of the soil solution. It is observed that at the very low range of NPK sensor value (refer Table 1) results in the low range of nitrogen which implies that urea should be necessarily added to the soil. Low and medium range of NPK sensor value result in adequate (medium) level of nitrogen in the soil. The high and very high range of sensor value results in the high value of nitrogen indicating the excess quantity of nitrogen present in the soil that implies to avoid added urea to the soil.

Fig. 11(b) shows the existence of phosphorous in the soil with respect to different NPK sensor value sensed from the sample of the soil solution. The observation is that at very low and low range of NPK sensor value results in the low range of phosphorus. Medium range of NPK sensor results in the adequate level of nitrogen and phosphorus in the soil. The high and very high range of sensor value results in the high value of phosphorus indicating the excess quantity of phosphorous present in the soil and hence usage of fertilizers like Di-ammonium phosphate is avoided

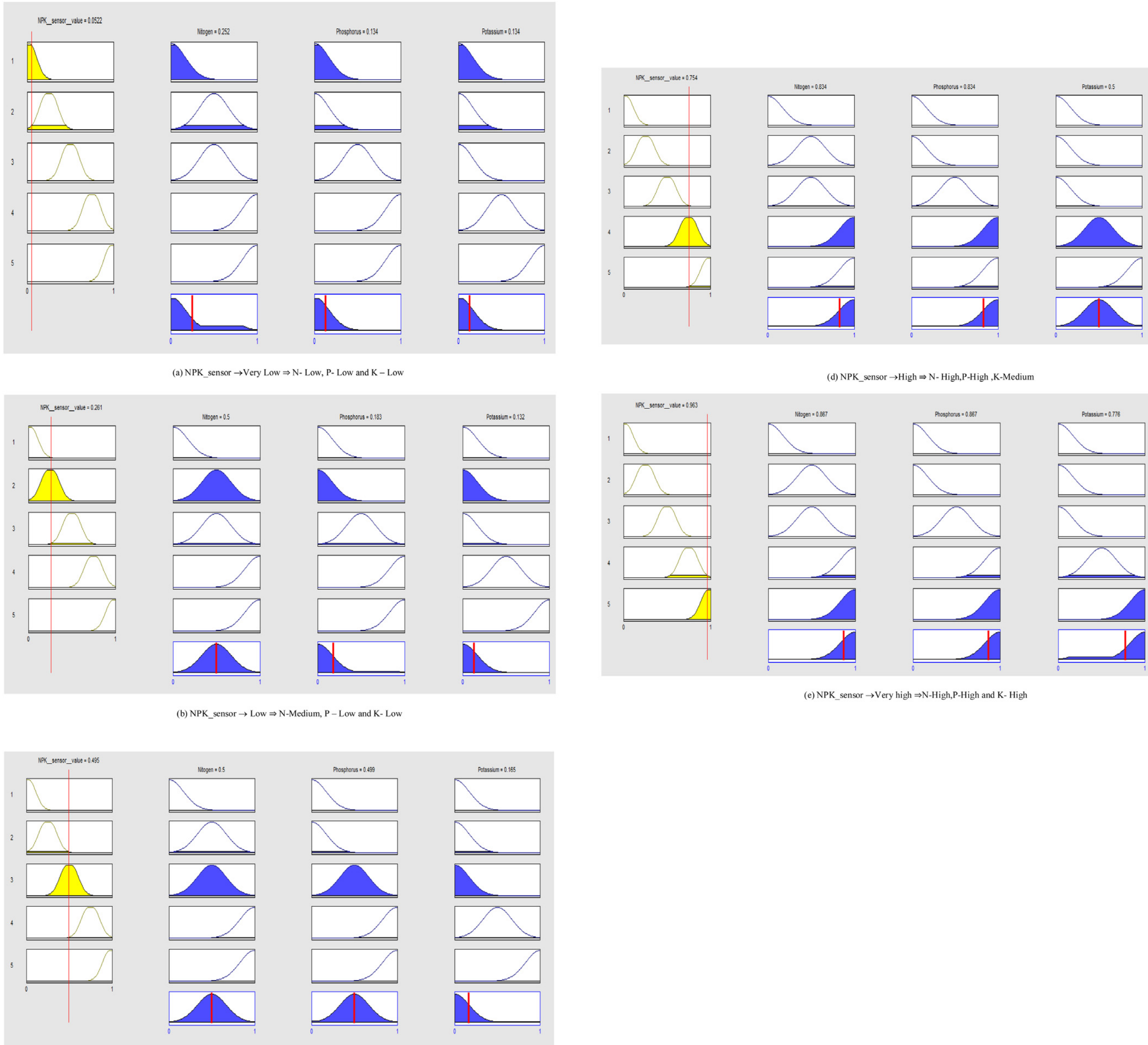
The variation of the presence of potassium level in the soil with the NPK sensor value is shown in Fig. 11(c). It is examined that at very low and low range of NPK sensor value results in the low range of potassium. Medium range of NPK sensor results in the adequate level of nitrogen and phosphorus in the soil with deficient in potassium. High range of sensor value results in an adequate level of potassium present in the soil and very high range of sensor value results in the high value of potassium indicating the excess quantity of potassium present in the soil.

Finally, the aggregation of the three output variable will lead to the decision of selecting the appropriate fertilizer for the automatically tested soil. It was analyzed that a fertilizer with the composition of N,P and K is added to the soil at very low and low range of NPK sensor value since the soil is found to be deficient in all the three major nutrients. Similarly, the medium range of sensor value implies to add the fertilizer with the composition maximum of potassium and minimum of phosphorus and nitrogen. No fertilizer is suggested to be added for a very high range of sensed value

Hence, the inference system response shown in Fig. 11(a–c) at the edge level of the proposed IoT device leads to the delivery of SMS through internet agents to the farmers about the appropriate use of fertilizer based on the nutrients level present in the soil.

6.2. IoT simulation results

This section describes the simulation of the proposed IoT system implemented as a wireless sensor network using Qualnet 4.0



(a) NPK_sensor →Very Low ⇒ N- Low, P- Low and K – Low

(b) NPK_sensor → Low ⇒ N-Medium, P – Low and K- Low

(c) NPK_sensor →Medium ⇒ N- Medium, P- Medium and K- Low

(d) NPK_sensor →High ⇒ N- High,P-High ,K-Medium

(e) NPK_sensor →Very high ⇒N-High,P-High and K- High

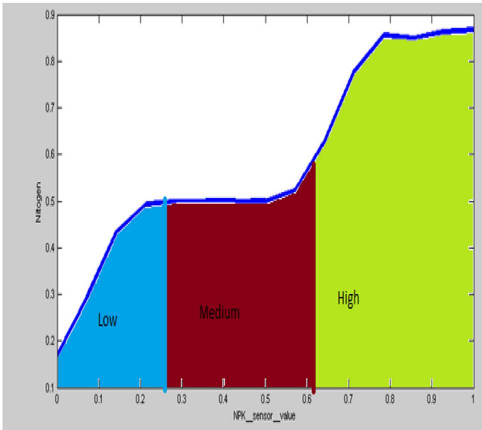
Fig. 10. Rules of Fuzzy inference system for soil nutrients testing (a) NPK_sensor → Very Low ⇒ N → Low, P → Low and K → Low. (b) NPK_sensor → Low ⇒ N → Medium, P → Low and K → Low. (c) NPK_sensor → Medium ⇒ N → Medium, P → Medium and K → Low. (d) NPK_sensor → High ⇒ N → High, P → High, K → Medium. (e) NPK_sensor → Very high ⇒ N → High, P → High and K → High.

simulator. The IoT layered protocol discussed in Section 4 is implemented in all the layers and simulated with the parameters shown in Table 3. The simulation is carried out to transfer data from NPK sensor kit to cloud server and analyzed the performance metric such as throughput, end to end delay and average jitter by varying the density of networks

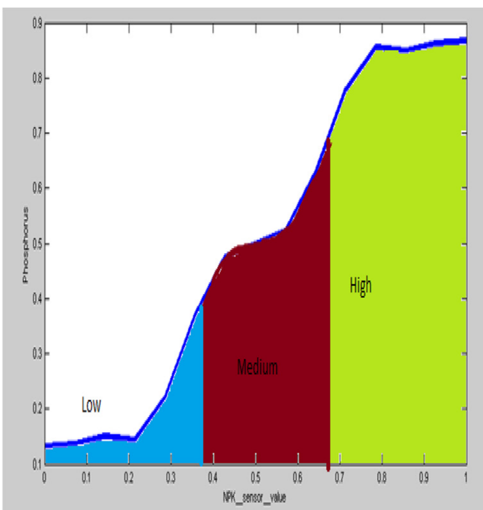
Protocols mentioned in Section 4 are implemented in C++ and included in the protocol list of the software. The executable C++ protocol files are included in the list of setting in each layer of the Qualnet architecture. Various scenarios for the same protocols are created and simulated to analyze the network performance. A sample scenario of 10 nodes is shown in Fig. 12. Similar scenarios are created with a single internet server and 5, 10, 15, 20, 25, 30, 35 and 40 nodes to investigate the performance with respect to measure the throughput, end to end delay and jitter. The performance of the network is analyzed with respect to scalability factor to examine whether that the proposed system can be implemented in real time

Table 3
Simulation parameters.

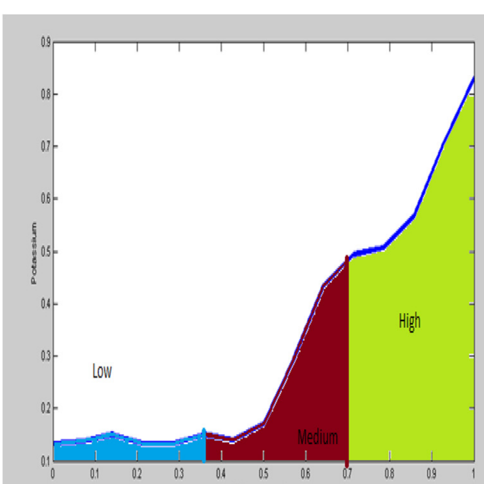
Sl.No	Parameters	Values
1	Simulation Time	300 s
2	Scenario Dimension	1500 m × 1500 m
3	Channel frequency	2.4 GHz
4	Pathloss Model	Free space
5	Propogation Limit	−111 dBm
6	Node Type	Static
7	Battery Model	Linear model
8	Battery Charge Monitoring Interval	60 s
9	Full battery capacity	1200 mA h
10	Transmission power	15 dBm



(a) presence of nitrogen in the soil



(b) Presence of phosphorus in the soil



(c) Presence of potassium in the soil

Fig. 11. (a) Presence of nitrogen in the soil. (b) Presence of phosphorus in the soil. (c) Presence of potassium in the soil.

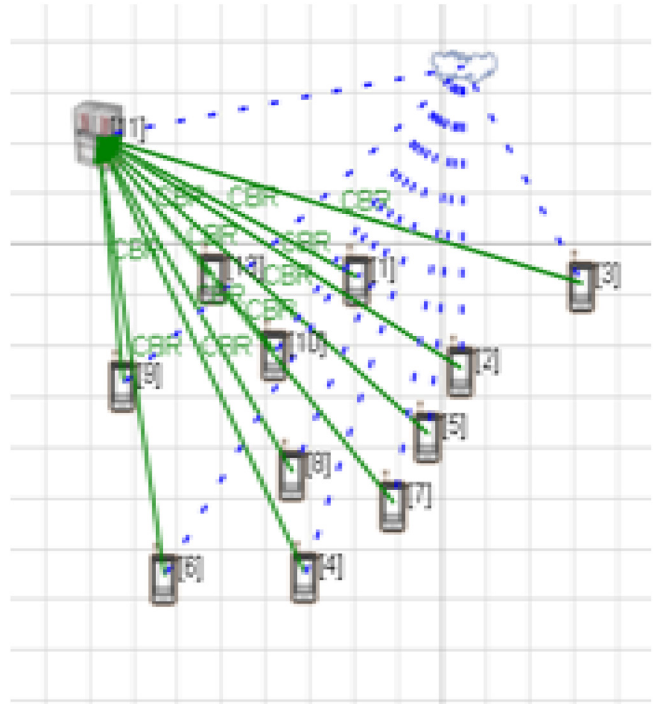


Fig. 12. Simulation scenario using 10 nodes.

to analyze the soil nutrients in any kind of agricultural fields. Thus, it leads to provide better analysis with regard to the fertilizer used and type of crops to be planted in a vacant land.

6.2.1. *Impact on energy consumption*

One of the main issues of wireless sensor networks is energy efficiency. The individual system of one unit to be fixed in an agricultural field can be a solar power battery. The energy consumed by the sensor is based on the active mode of the sensor. The sensor in the proposed system remains in the idle state for more than 24 h. The duration for regular soil nutrients measurement process takes minimum two or maximum three days i.e. approximately 36 h during the crop growth. The frequency of sensing and data transmission to the cloud is very less and it depends on the crops that are grown in the respective agricultural field. In this simulation, the data transmission frequency is varied for certain sensors to show that the energy consumption is high only when the sensing period of the regular interval is less. Energy consumed by the individual sensor for the 10 node scenario is shown in Fig. 13. It is observed that the energy consumed by each NPK sensor is approximately less than 0.14 mJ for sensing, edge analysis and data transmission

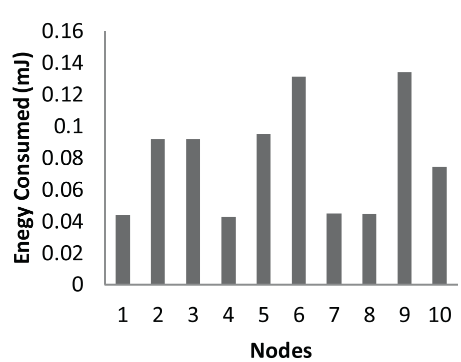


Fig. 13. Energy consumption for 10 node scenario.

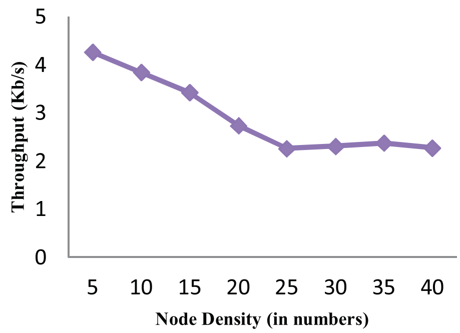


Fig. 14. Throughput variation vs. node density.

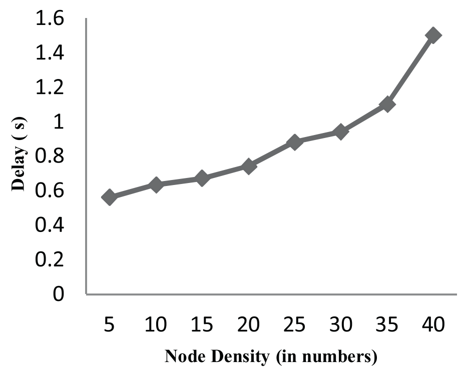


Fig. 15. Delay variation with node density.

6.2.2. Impact on throughput

Throughput is the measure of data transfer rate of the network and it varies proportionately with the density of the networks. To analyze the variation of throughput, the frequency of data transmission is fixed constant. It was observed that the throughput attains a saturation level above the node density 20 as shown in Fig. 14.

6.2.3. Impact on delay

Fig. 15 shows the average end to end delay for the various densities of the network and it is measured as the time taken for the data transfer from the sensor to the server (considered to be cloud database). It is observed that the average delay increases as the node density increases due to the more congestion during data transmission through the common network.

6.2.4. Impact on jitter

Jitter indicates the average variation in the delay of packets received by the cloud database in the proposed system. Average jitter is observed to be very less of around 5 ms whose variation with respect to node density is shown in Fig. 16.

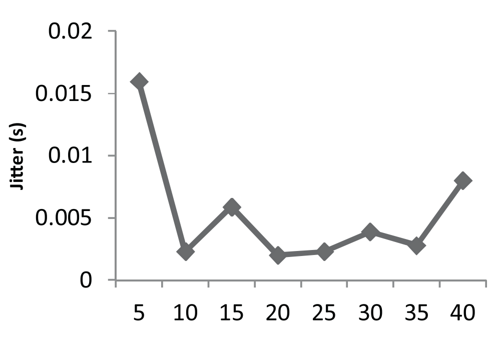


Fig. 16. Jitter variation with node density.

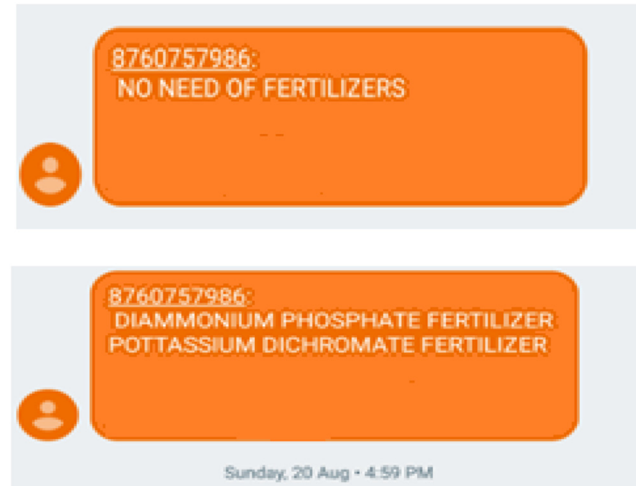


Fig. 17. Sample SMS generated during soil nutrients analysis.

It is clear from the simulation results that the proposed system can be implemented as a wireless sensor network in a rural region which comprises of large agriculture sector. The performance seems feasible, employable and scalable.

The inference system output at the edge level leads to a delivery of SMS through internet agents about the appropriate use of fertilizer based on the present soil nutrients level. Fig. 17 shows the screenshot of the SMS sends to the mobile phone through the Internet. It reports that fertilizer is not required for the soil sample 1 which has all the three macronutrients- Nitrogen, Phosphorus and Potassium in the adequate level. The second SMS reports the farmer about the fertilizer to be added to the soil that is deficient in phosphorus and potassium.

Through the SMS facility, the proposed can be an effective product for the farmers to increase the yielding of crops by adding the appropriate fertilizer at the right time based on the nutrients level.

7. Conclusion

Fortitude of soil nutrients determination regularly in the agricultural field is difficult due to manual testing in laboratories. It causes the negligence to the farmers about the nutrient level in the soil and improper use of fertilizer at the inappropriate time. The proposed system provides the farmer regarding the deficiency of major soil nutrients namely nitrogen, phosphorous and potassium through SMS using the designed NPK sensor with its fuzzy rule-based system. Experimental simulations are carried out to understand the functionality and inform the intended purpose of the developed IoT system. From the experiment, it is clear that the proposed system is a low cost, accurate and intelligent IoT system that intimates the farmer about the fertilizer to be used at right time automatically through SMS and can be used as a helping tool for the farmers in agriculture purpose.

Author contributions

Lavanya conceived and designed the NPK Sensor. Rani Chellasamy contributed the analysis tools. Ganeshkumar Pugalendhi developed the Fuzzy Rule Based System. Lavanya conducted simulation and performed the experiments; Lavanya and Rani Chellasamy wrote the paper; Ganeshkumar Pugalendhi corrected and revised the paper.

Conflicts of interest

The authors declare that no conflicts of interest.

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