Development of wireless data acquisition system for soil monitoring

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Abstract. Agriculture is getting more inclined with modern technology. Automatic data acquisition of soil condition with the help of a sensor lessens the time and manual work in testing a soil if it is suitable for planting. However, soil characteristic changes periodically. Thus, determining the macronutrients present in the soil is always a challenge for the currently available sensors because most of them can only get and give one or two information from the soil simultaneously. This research focused on the development of a digital single probe sensor to monitor the macronutrient contents of the soil, i.e. nitrogen, N; phosphorus, P; and potassium, K. Moreover, the soil’s temperature, moisture, and pH level were also monitored. In order to obtain the N-P-K content, a rod electrode or probe, which produces electrical potential in response to the reading, was utilized. The electrical conductivity of the soil provides the N-P-K values and the electrical resistivity of the soil gives the soil’s pH and moisture content. A canister for storing and releasing the reagents to enhance the sensor’s conductivity is installed and once the probe is injected in the soil, a button can be pressed to release the reagents to the soil. Moreover, a Wi-Fi module was installed in order for the user to monitor the data collected by the device. The calculated percentage error of the device in monitoring soil fertility is 12%.

Keywords: NPK sensor, single probe sensor, soil monitoring

1. Introduction

Nowadays, agriculture is getting more inclined with modern technology [1] as technical advances in electronics, digital signal processing, sensors, and wireless communication are growing faster and steadily throughout time. The use of these smart gardening devices such as cordless hedge trimmer and robotic mower has enabled the field of agriculture to adapt to the continuous challenges of sustainability, producing more crops to feed the ever increasing population. To fulfil the endless need for consumer satisfaction, these modern agricultural devices are redesigned to contain an increasing number of sensors; hence, making their applications more customized for ease of use.

The need to monitor soil fertility is of utmost importance for farmers growing a variety crops. Automatic acquisition of data from the soil with a help of a sensor lessens the time and manual work of an individual in testing a soil for planting. However, soil characteristic changes periodically. Determining the macronutrients present in the soil is always a challenge for the garden sensors currently available because most of them can only get and give one or two information from the soil simultaneously.
Several studies on such agricultural devices were found in literature. A study [2] on analysing soil pH and nutrient using colorimetry was done. The N-P-K levels and pH of the soil was monitored by using synthetic compounds that is color sensitive for each of the target nutrient. Several trials were done to know the color response of the reactants that served as the reference for each nutrient. RGB values were extracted using TCS3471 color sensor and an LDR color sensor. The device was tested using three samples each of every nutrient and pH with ten trials each. It was concluded that there was no significant difference between the proposed device reading the soil pH and nutrient content and the human resource reading.

Moreover, a study [3] to monitor soil moisture using an Arduino-based system was conducted. The researcher developed a modular and flexible system using cheap and affordable components. The device used for the system to determine the soil moisture measurement is Watermark 200SS soil moisture sensor. Watermark 200SS soil moisture sensor measures electrical resistance inside of a granular matrix in order to determine soil water tension. The system was flexible and can be used for real-time monitoring. Also, the water content depends on the outer appearance and characteristic of the soil; likewise, the sensor measures the water potential. By determining the moisture retention curve, the correlation between the water potential and the moisture content of the soil was acquired.

The use of Raspberry Pi and Internet of Things (IoT)-based monitoring and controlling devices for agriculture was also studied. The data gathered from the soil is transferred into cloud and can be accessed by using IoT. This study had no human interaction in their test monitoring. The output data gathered were soil moisture, temperature and humidity of the specific field. The objective of the research was to enhance the effectiveness of agriculture by integrating IoT with Raspberry Pi. If soil temperature is high, the pumping motor will be switched on automatically by the use of relay. After collecting data, it will be sent to the main server using the said microcontroller and showed using LCD display [4].

The primary focus of this research is to lead an innovative approach in monitoring and updating the soil quality information through a digital device. The study aimed to implement a system capable of acquiring temperature, moisture, pH level, and N-P-K values of the soil simultaneously to track soil fertility. Data were acquired wirelessly for versatile accessibility and with no delay. Part of the system was a single probe that can gather different data in a single device.

2. Methods
The determination of the soils N-P-K contents, the levels of the soil’s pH and moisture, and the temperature of the soil was designed such that a single device with a single probe will be utilized.

2.1 Project Design
Figure 1 shows the block diagram of the system. The data from the sensors for temperature, moisture, pH, and the macronutrients N-P-K serves as the input of the system. The Arduino gathers and processes these data. The Raspberry Pi is incorporated with a Wi-Fi module for the user to be able to access the data gathered through the internet. All these operations pass through both the microcontroller program. The output of the system is seen through a liquid crystal display (LCD) screen and can be accessed through Wi-Fi.

Figure 2 shows the flow diagram of the process used for determining the levels of N-P-K in the soil. The soil sample is mixed with reagents to initiate a chemical reaction. Different substances are added and the color sensor determines the levels of the macronutrients in the sample soil. All the output of the sensors is displayed on LCD screen.
2.2 Operation Testing and Procedure
A soil test kit is used to acquire and gather the given parameters of the soil using a manual testing procedure. This manual test is the basis of the project on how the researchers come up with a value that will be shown to the user. A soil sample is tested in a laboratory and the results from the laboratory soil test and the device is compared for reliability of the proposed devised.

To obtain the desired result for knowing the values acquired by the sensors in the given soil sample, the number resistance and voltage of the soil is calculated to get the final value. The equations used in Arduino are as follows:

\[
\text{pH} = \frac{1024 - A_1}{10.22} \quad (1)
\]

\[
\text{Mois} = \frac{pK + pot}{2} \quad (2)
\]

Nitrogen = 1024 – pot \quad (3)

Phosphorus = 1024 – pk \quad (4)

Potassium = \frac{1024 - pK}{3.2} \quad (5)

Temperature = \frac{1024 - temp}{8} \quad (6)

Moisture = 1024 – Mois \quad (7)

where pH is the pH level, Mois is the resistivity of the soil, pk is the analog voltage on pin A0, pot is the analog voltage on pin A2, and A1 is the analog voltage on pin A1. The values for N, P, and K are in parts per million (ppm); for temperature, Celsius; and for Moisture resistivity, Ohms.
3. Results
3.1 Prototype
A switch button is used to power on the device located at the side of the prototype. Upon starting the device, a view showing the parameters is displayed on the screen shown in the figure below. An alarm display will be shown if the device needs to be recharged. Moreover, the data are stored, recorded and can be accessed through a Wi-Fi module connected to a wireless device. A display of the previous and present records can be seen once the IP address is accessed.

![Screen display when the prototype was power on](image1)

**Figure 3.** (a) Screen display when the prototype was power on, and (b) Sample display of present record of data.

![Casing of the prototype](image2)

**Figure 4.** Casing of the prototype.

The device also uses a button that releases a chemical to the soil that is acquired by the prototype. The chemicals are used to short the sensors. Three metal rods are set to sense the parameters when the chemical is dropped between them. If the iron and aluminum rod are shorted, the pH is measured; when iron and zinc are shorted, potassium level is acquired; and if aluminum and zinc are shorted, nitrogen and phosphorus level are measured. The moisture is measured through the resistance of the soil.
3.2 Prototype Calibration

A manual testing with the use of the soil test kit was made initially. Two types of soil were used to compare each of the results if the values obtained were comparable. The first soil sample used was from a backyard garden from Laguna, Philippines and the second soil sample was from Bulacan, Philippines. The soil samples were divided – some were dried and some were wet. These soil samples were separated and each mixed with distilled water. After mixing, the soil slurries were allowed to settle for about 24 hours.

Once the soil subsided from the water, the water was collected and transferred to the soil test kit and mixed with a chemical reagent, after which the color was compared with the soil test kit. The results were used as a base data for the calibration of the prototype. Table 1 shows the result of the two soil samples. Figure 6 shows the soil test kit color chart.

### Table 1. Manual Test Result of the Two Soil Samples.

| Parameters       | Trial 1 | Trial 2 | Trial 3 | Trial 4 |
|------------------|---------|---------|---------|---------|
| **Laguna Soil Sample** |
| pH               | Neutral | Alkaline | Neutral | Alkaline |
| Nitrogen         | Depleted| Depleted | Deficient| Adequate |
| Phosphorus       | Deficient| Adequate | Adequate| Adequate |
| Potassium        | Failed  | Deficient| Adequate| Sufficient |
| **Bulacan Soil Sample** |
| pH               | Alkaline | Alkaline | Alkaline| Alkaline |
| Nitrogen         | Deficient| Adequate | Deficient| Deficient |
| Phosphorus       | Sufficient| Adequate | Deficient| Adequate |
| Potassium        | Failed  | Deficient| Adequate| Sufficient |

### Table 2. Results of Soil Moisture and Temperature Using Standard Sensors and Prototype Testing.

| Parameters | Moisture | Temperature |
|------------|----------|-------------|
| **Trial 1** |
| Other Sensor | 72       | 29.3        |
| Device      | 86       | 22.9        |
| **Trial 2** |
| Other Sensor | 55       | 31.4        |
| Device      | 70       | 26.8        |
| **Trial 3** |
| Other Sensor | 76       | 28.1        |
| Device      | 84       | 23.2        |
| **Trial 4** |
| Other Sensor | 70       | 24.2        |
| Device      | 76       | 25.1        |
3.3 Process of the Device

The process of reading and accumulating data of the soil involves several steps. The device needs to be turned on before injecting into the soil. A switch button is used to start the device, once the device is injected into the soil, a second button is assigned for the servo motor to be operated. This button must be tapped so that a drop of a liquid chemical will be released into the soil before the sensors start to read the values. These chemicals work as a bridge for the sensors to read the N-P-K values. This process is called Electrochemical Method which involves the measurement of electrical signals associated with chemical systems. It is a quantitative method of analysis based on electrochemical phenomena occurring within a medium or at the phase boundary and related to changes in the structure, chemical composition or concentration of the compound being analysed. The six rods present in the device serve as the electrochemical sensors. Once the button for servo motor is pressed, a liquid chemical used to amplify the electrodes will be discharge into the soil. These chemicals will have an electrochemical reaction and the ions will be read by the sensor rods.

The humidity has a negative effect with the sensor especially when the water level is high, the Raspberry Pi is sensitive to high humidity and has a tendency to be compromised if ions from the soil is greater than what is supposedly supplied to it, since high humidity in soil gathers high charges of ions from it.

The values read by the sensor rods where being passed through the Arduino to Raspberry Pi. The Raspberry Pi serves as a tool for the Arduino to have a communication with the HTML. The Arduino gathers all the data acquired by the sensors while Python does the data acquisition. The JavaScript and the HTML is the heart of the system, wherein the JavaScript do all the works pertaining in the execution of the program while the HTML saves all the data acquired and processed by the system.

4. Conclusion

The device was able to acquire the parameters of the soil simultaneously to track its soil fertility with a percentage error of 12%. The laboratory certifies that the results obtained by the prototype were indeed valid at the moment of calibration and that the calibration of the measuring device used for the data are read after stabilization. The device will productively save time in monitoring the soil and acquiring its data as the previous and current values were stored in the record and can be accessed anytime. The device was also easy to use and handle as it is a portable device.

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