ORIGINAL ARTICLE

INTERNATIONAL JOURNAL OF ARTIFICIAL INTELLIGENCE

ISSN: 2692-5206, Impact Factor: 12,23
American Academic publishers, volume 05, issue 05,2025

Journal: https://www.academicpublishers.org/journals/index.php/ijai

SMART MONITORING SYSTEM FOR DETERMINING THE AMOUNT OF MACROELEMENTS ENSURING HEALTHY PLANT GROWTH

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Annotation: This article provides information about sensors and automated systems based on artificial intelligence used to detect macroelements in soil in agriculture. In the Republic of Uzbekistan, the level of automation in the agricultural sector is developing at a moderate pace. The level of automation in Uzbekistan's agriculture is currently around 10-20%, and these technologies are mainly widely used in large farms and agrarian enterprises. In small and medium farms, these processes are still developing, and in the future, additional incentives and infrastructure development by the state are required to create more opportunities for them.
This article analyzes methods of measuring soil composition using a combination of Arduino and Soil NPK Sensors and displaying this data on an OLED display or through an Android application. The principles of operation of the Soil NPK Sensor, its technical specifications, and its integration with Arduino are thoroughly covered in this article.

Keywords: Arduino, NPK sensor, nitrogen, phosphorus, potassium, OLED display, RS485 (MAX845) module, Bluetooth

Introduction

Soil fertility is one of the important factors for healthy plant growth and high yield. Out of the 17 essential elements required for plant vital activity, 14 are taken from the soil, while three elements are absorbed through air and water. Among these elements, nitrogen (N), phosphorus (P), and potassium (K) are considered the most important and are widely used in commercial fertilizers. Therefore, accurate measurement and monitoring of soil NPK content is of great importance in creating optimal conditions for plants.

Development of Soil NPK Sensors:

NPK sensors consist of several types of devices developed to measure the level of nutrients in the soil. These sensors offer a much more convenient, economical, and efficient alternative compared to traditional laboratory analyses. The sensors are distinguished by their small size, affordability, low power consumption, and fast accuracy. The main direction of sensor development is to make them even more compact, affordable, and efficient.

Internet of Things (IoT) and Machine Learning Technologies:

In recent years, IoT technologies and machine learning (ML) methods have been widely used to monitor soil and determine its composition. IoT systems help to transmit data collected through sensors to the network and enable remote monitoring. ML technologies, in turn, make it possible to make accurate predictions about soil composition based on the data collected by sensors. With the help of ML, it is possible to accurately predict the levels of nutrients (N, P, K) in the soil, which helps farmers to allocate their resources efficiently.

Traditional and Modern Methods:

Methods used to study soil are divided into two groups: traditional and modern. Traditional methods are carried out through laboratory analyses, but they require time and resources.

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Modern methods, on the other hand, ensure timely and efficient results through sensors, IoT systems, and ML. At the same time, new technologies help make soil monitoring faster and more affordable.

Future Prospects:

The development of sensors and IoT systems creates new opportunities for monitoring soil in the agricultural sector. Among the areas being studied, the development of highly accurate, widespread, and affordable sensors deserves special attention. Additionally, with ML and IoT technologies, it becomes possible to analyze soil data in real-time and make effective decisions based on the results.

Analyzing the work of scientists who have implemented automation in agriculture helps to better understand innovative approaches and the growing role of technologies in this field. The introduction of automation technologies into agriculture has created opportunities for farmers to increase efficiency, save resources, and ensure ecological sustainability. Below is an analysis of the work carried out by scientists in this field, including their achievements and shortcomings.

Several scientists have conducted research on automating fertilization processes. For example, in a study conducted by Zhang et al. (2020) [1], a system was developed aimed at optimizing the fertilization process using NPK sensors and IoT systems. According to the research results, real-time soil monitoring allowed for accurate determination of fertilization quantities and enabled effective management of this process. Their work is important from the perspective of increasing soil fertility and reducing ecological footprint.

Lee et al. (2019) [2] conducted research related to the automation of irrigation systems and developed methods to optimize irrigation through the application of IoT and artificial intelligence. In their work, the efficiency of the irrigation system was improved using soil moisture measurement sensors and AI algorithms. The system automatically monitors the amount of water in the soil and performs fertilization and irrigation at the required time. This method not only saves water but also helps improve crop quality.

Kumar et al. (2021) [3] considered an approach aimed at developing mobile applications and remote monitoring systems in their research. Their work confirmed the effectiveness of remotely monitoring soil conditions, obtaining real-time NPK measurements, and continuously providing farmers with information. Through mobile applications, the condition of the land on farms is quickly analyzed, and farmers can make correct decisions about fertilization or irrigation. This approach is especially useful for small and medium farmers because they can apply modern technologies at low cost.

In the study conducted by **Santos et al. (2020) [4]**, the use of automated agricultural machinery (for example, robotics and artificial intelligence in tractors) was analyzed. According to the results of the study, through the automation of fertilizing the land, preparing the soil, and harvesting processes, it was possible to achieve a 40% increase in efficiency. The systems they proposed demonstrated the possibility of saving resources and time, increasing labor productivity, and reducing ecological footprint.

In the work carried out by **Zhang and Chen (2021) [5]**, automated systems were developed through the use of artificial intelligence in agriculture. They proposed innovative solutions using algorithms focused on data analysis, fertilization optimization, and biodiversity conservation. With the help of AI systems, it is possible to automatically forecast soil characteristics and take necessary measures. These technologies play an important role not only in increasing efficiency but also in ensuring ecological sustainability.

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The application of automation systems in agriculture faces several challenges. The high cost of comparison and monitoring systems and the different responses of soil under varying conditions can hinder the effective operation of the system. For small farmers, implementing these technologies is often financially difficult, as the purchase and installation costs of advanced technologies are high. Also, the limited availability of technical and scientific knowledge can sometimes cause problems in effectively operating the systems. This article provides information about creating one such project and its practical implementation.

Methods

Information about the sensors and actuators used in this project was provided in our previous articles [6].

The smart monitoring system for plant growth integrates several sensors and actuators on the Arduino platform. To build this system, the following components are used:

- **Soil NPK Sensor** (a sensor that measures soil composition)
- **Arduino Nano** (main control module)
- **MAX485 RS-485 interface** (for data exchange via the Modbus protocol)
- **SSD1306 OLED display** (for displaying soil components)
- **HC-05 or HC-06 Bluetooth module** (for connection with an Android application)
- **12V power supply** (for the sensor and Arduino)

The Soil NPK sensor operates via the Modbus RTU protocol and connects to the Arduino through the RS485 interface. The sensor functions at a voltage of 9V–24V and accurately measures soil composition in mg/kg units.

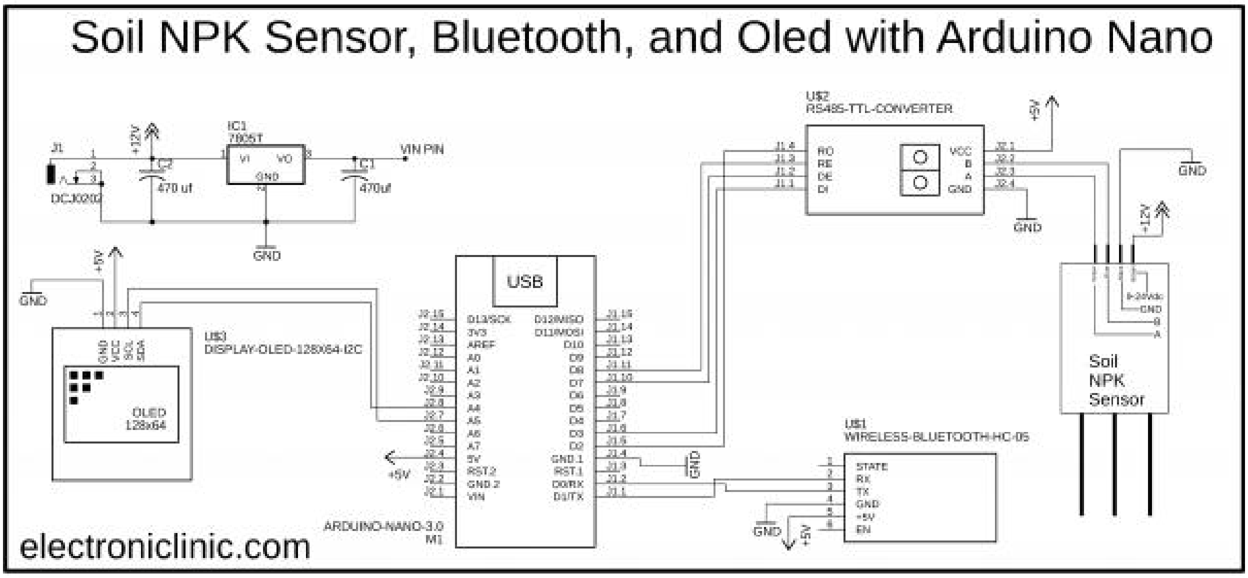

Figure 1. Connection diagram of the system project for determining soil macroelements. (**From right to left:** NPK sensor, Max485 module, Bluetooth, Arduino NANO, OLED display)

Device connection scheme: (Table 1)

The interconnection of the Soil NPK Sensor is carried out according to the following scheme:

- The **VCC pin** of the sensor is connected to a **12V power source**.
- The **GND pin** is connected to the **Arduino GND pin**.
- The **A and B pins** are connected to the corresponding pins of the **MAX485 interface module**.

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- The **RO and DI pins** of the MAX485 interface are connected to **Arduino D2 and D3 pins**.
- The **TX and RX pins** of the **HC-05 Bluetooth module** are connected to the **Arduino RX and TX pins**.
- The **OLED display** is connected to **Arduino A4 (SDA)** and **A5 (SCL)** pins.

Table 1. Connection status of project devices:

Device	Pin	Connection Piont
NPK sensor	VCC	12V quvvat manbai
	GND	Arduino GND
	A	Max485 A
	B	Max485 B
MAX485	VCC	Arduino 5V
	GND	Arduino GND
	RO	Arduino D2
	DI	Arduino D3
	DE/RE	Arduino D4
	A	NPK Sensor A
	B	NPK Sensor B
HC-05 Bluetooth	VCC	Arduino 5V
	GND	Arduino GND
	TX	Arduino D0 (RX)
	RX	Arduino D1 (TX)
OLED Displey	VCC	Arduino 5V
	GND	Arduino GND
	SDA	Arduino A4
	SCL	Arduino A5

Software and Modbus Requests:

In the Arduino program, the **SoftwareSerial** and **Modbus** libraries are used. The sensor is controlled using the following Modbus commands:

- To read Nitrogen (N): 0x01, 0x03, 0x00, 0x1E, 0x00, 0x01, 0xE4, 0x0C
- To read Phosphorus (P): 0x01, 0x03, 0x00, 0x1F, 0x00, 0x01, 0xB5, 0xCC
- To read Potassium (K): 0x01, 0x03, 0x00, 0x20, 0x00, 0x01, 0x85, 0xC0

The program sends these commands sequentially and displays the results on both the **OLED display** and the **Android application**.

Several libraries are used in writing the code section of the program. Before executing the loop() and setup() functions, the operational status of the existing devices is declared. Below is a sample code for the introduction part of the program.

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```
#include <SoftwareSerial.h>
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>

// For the i2c supported Oled display module which is 128x64
#define SCREEN_WIDTH 128    // OLED display width, in pixels
#define SCREEN_HEIGHT 64    // OLED display height, in pixels
#define OLED_RESET -1       // Reset pin # (or -1 if sharing Arduino reset pin)
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET);

#define RE 8
#define DE 7

// The following are the Inquiry frames which are send to the NPK sensor
//for reading the Nitrogen, Phosphorus, and Potassium values
// We defined three arrays with names nitro_inquiry_frame, phos_inquiry_frame, and p
// Each inquiry frame have 8 values
const byte nitro_inquiry_frame[] = {0x01,0x03, 0x00, 0x1e, 0x00, 0x01, 0xe4, 0x0c};
const byte phos_inquiry_frame[] = {0x01,0x03, 0x00, 0x1f, 0x00, 0x01, 0xb5, 0xcc};
const byte pota_inquiry_frame[] = {0x01,0x03, 0x00, 0x20, 0x00, 0x01, 0x85, 0xc0};

byte values[11];
SoftwareSerial modbus(2,3);
```

Results

The developed program code section is uploaded to the Arduino microcontroller using the **Arduino IDE** software. After running the program, the **NPK sensor** is placed into the soil where values need to be measured. Under the proper conditions, the values can be observed on the **OLED display**.

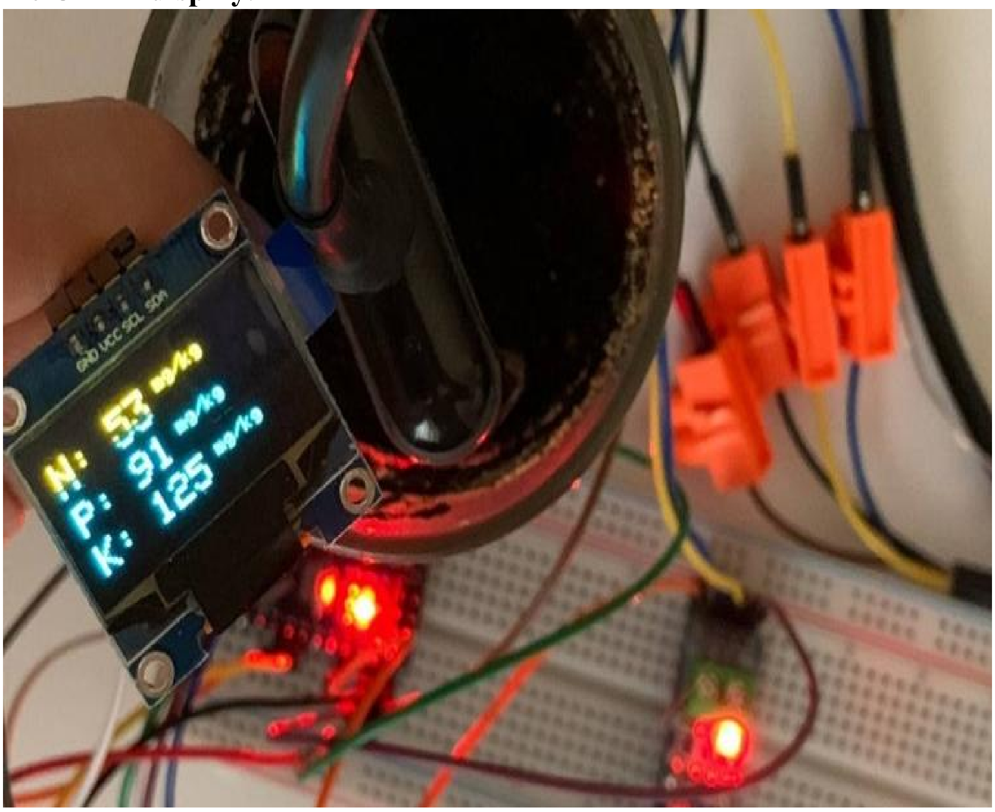

Figure 1. Display view of the measured values on the OLED screen

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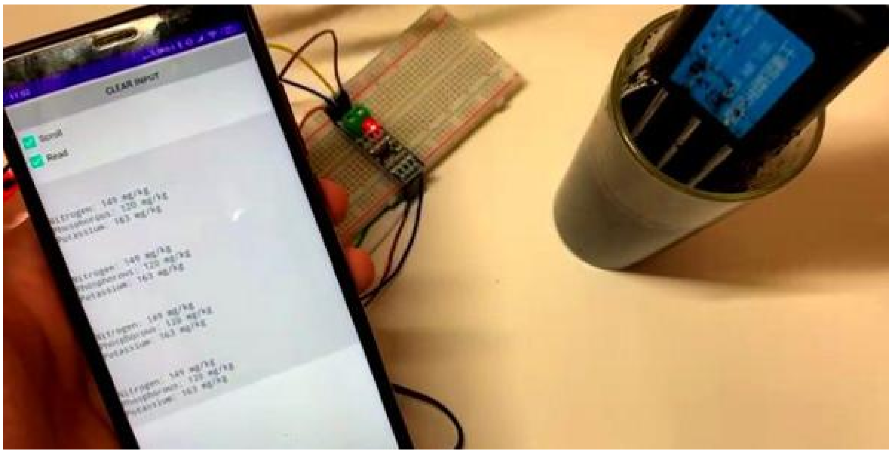

Figure 2. Display view of the measured values on an Android phone

The system was tested and the following results were achieved:

1. The accuracy of the Soil NPK Sensor was up to ±2% F.S., and experimental results gave satisfactory outcomes when compared to standard laboratory tests.
2. Real-time data was displayed through the OLED screen, enabling rapid monitoring for farmers and researchers.
3. Data was transmitted to an Android application via the HC-05 Bluetooth module, allowing users to remotely monitor soil composition via the app.

Discussion

The research results showed that the combination of the Soil NPK Sensor and the Arduino platform can be an effective solution for developing a smart monitoring system in agriculture. The system has the following advantages:

- **Portable and user-friendly:** The device is easy to move and can be used to measure any type of soil.
- **Affordable and cost-effective:** While NPK measurement in commercial laboratories is expensive, this system provides accurate results at a low cost.
- **Remote monitoring capability:** Real-time monitoring is possible via an Android app through Bluetooth.

However, the system also has certain limitations:

- The sensor operates only within a temperature range of **5°C to 45°C**, meaning results may be inaccurate in very cold or hot conditions.
- Measurements are limited to the **0–1999 mg/kg** range; if the nutrient levels in the soil exceed this range, additional testing is required.

Conclusion

The development and implementation of technologies in the field of soil monitoring provide farmers with the opportunity to achieve higher yields and use resources efficiently. The integration of sensors, IoT systems, and machine learning technologies will significantly optimize the processes of soil management and monitoring in the future.

In this article, a system for monitoring soil fertility was created based on **Arduino** and a **Soil NPK Sensor**, and it was tested through experiments. The system is accurate, fast, and user-friendly, and can be widely used in agriculture and scientific research.

This innovative approach to soil monitoring helps farmers optimize the fertilization process, increase crop productivity, and utilize resources more efficiently.

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ISSN: 2692-5206, Impact Factor: 12,23

American Academic publishers, volume 05, issue 05,2025

Journal: https://www.academicpublishers.org/journals/index.php/ijai

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