Detection of Nitrogen, Phosphorus, and Potassium (NPK) nutrients of soil using Optical Transducer

Sheikh Sayed Bin Rahman*, Ishfaq Ahmed , Noble Mozumder,
Israt Jahan leona , Fardin Mahmood.

Abstract—An optical transducer has been developed to measure and detect the presence of Nitrogen (N), Phosphorus (P), and Potassium (K) in soil. This transducer is essential for determining the additional amounts of these nutrients needed to enhance soil fertility, thereby improving soil quality and minimizing the unnecessary use of fertilizers. The N, P, and K levels in the soil sample are determined by the light absorption characteristics of each nutrient. The optical transducer functions as a detection sensor, comprising three LEDs as light sources and a photodiode as the light detector. The wavelengths of the LEDs are selected to match the absorption bands of each nutrient. The nutrients absorb the LED light, and the photodiode converts the remaining light, reflected by a reflector, into current. An Arduino microcontroller is used for data acquisition, converting the transducer's output into a digital display reading. Tests on various soil samples demonstrated that the optical transducer can assess the soil's NPK content as High, Medium, or Low.

Keywords—Optical transducer, NPK soil, LED, photodiode, Arduino.

I. INTRODUCTION

In today's world of advanced technology, various innovations have been developed to simplify daily human activities. In agricultural technology, numerous tools have been created to assist farmers in their agricultural practices and help them achieve good crop yields. One crucial factor for a successful harvest is the presence of adequately fertilized land. Proper fertilization aids plants in producing high-quality and abundant yields, which is essential to meet the growing global demand for food. To enhance crop quality and quantity, soil must contain sufficient nutrients, particularly Nitrogen (N), Phosphorus (P), and Potassium (K). These three essential nutrients support plant growth in different ways [1]: Nitrogen encourages leaf and vegetative growth, Phosphorus supports root development and overall growth, and Potassium aids in flowering, fruiting, and the regulation of nutrient and water within plant cells.

Previous researchers have developed NPK detection devices using various methods, including optical, electrochemical, acoustic, electrical and electromagnetic, and mechanical techniques [2]. Recently, the optical detection method has been recognized for its high potential in real-time detection due to its extreme sensitivity and rapid response [3]. Several studies on NPK soil detection using the optical method have been documented [1, 4-6], where the soil is illuminated by a light source and the absorption rate is measured by a light detector. Most of these developed devices utilize additional optical components, such as fiber optics, to direct the light to the soil [4, 5].

In this study, the optical detection method based on the absorption principle is employed due to the inherent optical properties of NPK soil. This detection method is considered direct because it does not require any additional components. LEDs are used as the light source, and the soil interacts by absorbing the light. The remaining light is detected by a photodiode, which evaluates the absorption rate by converting the light into current. The output from the photodiode is processed using an Arduino microcontroller, which converts and displays the output current as readings voltages.

II. METHOD

Figure 1 illustrates the overview of the optical transducer for detecting NPK in soils. The optical transducer integrates a light transmission system with a light detection system. The Arduino microcontroller controls the light source within the transmission system and is also responsible for data acquisition from the light detection system. Additionally, it manages the liquid crystal display (LCD) functions to operate the display.

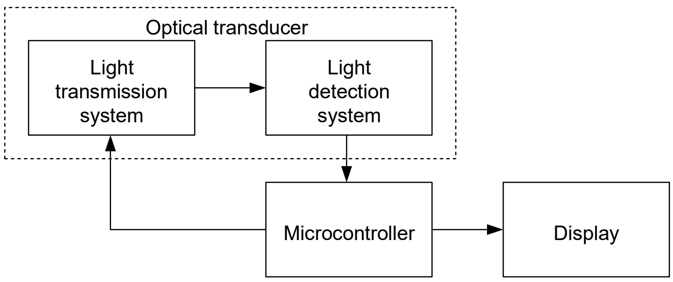

Fig. 1. Block diagram of integrated optical transducer with microcontroller

The light transmission system uses three LEDs with different wavelengths, each selected based on the absorption spectrum of NPK soils. Table I details the optical characteristics of NPK soil absorption and the corresponding LED emissions. In the light detection system, a photodiode sensor module serves as the light detector. The photodiode, a semiconductor, converts light into current. It receives light reflected from the soil, which is initially illuminated by the LEDs. This light is converted into current by the photodiode, and the data is then sent to the Arduino controller for further processing, such as digital conversion and display. The complete optical transducer with the microcontroller is shown in Fig. 1, and the schematic diagram is depicted in Fig. 2.

TABLE I. OPTICAL CHARACTERISTICS OF NPK SOILS AND LED EMITTANCE

Nutrient	Absorption wavelength (nm)	LED type	Wavelength (nm)
Nitrogen (N)	438-490	LED 1	460-485
Phosphorus (P)	528-579	LED 2	500-574
Potassium (K)	605-650	LED 3	635-660

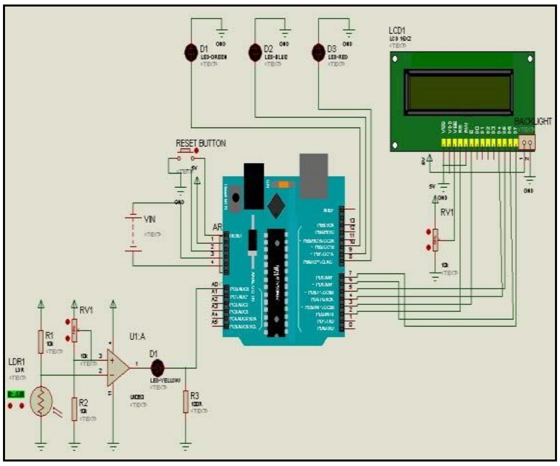

Fig. 2. Schematic diagram for overall optical transducer integrated with Arduino microcontroller

A. Experimental Set-Up

Before conducting the soil test measurement, the transducer was initially optimized by varying the distance between LED, reflector and photodiode sensor module as shown in Fig. 3 During measurement, the LED and the photodiode was positioned in parallel facing both in the same direction. The light gets reflected by the reflector and get detected by the photodiode. The effect of the incident light emitted to the detector was investigated to determine an optimum optical path length of the transducer. The LED substantially collimated the incident light in the range from 1 to 4 cm based on the requirement The measurements were conducted by varying the distance between the LED and the photodiode, from the shortest to the longest distance, as per the LED datasheet. The soil absorption measurement was carried out using the developed optical transducer on six different soil types, as illustrated in Fig. 4. Three soil types with varying nutrients were sourced from a nursery shop, while the other three were collected from residential areas. The sample specifications are listed in TABLE II. Each soil sample, with an optimal thickness, was placed on a reflector and illuminated with LED light. According to Beer's Law, absorbance (A) is defined by the following relationship:

$$A \log_{10} \frac{I_I}{I_0} \qquad (1)$$

where I_1 is the transmitted light and I_0 is the incident light [7]. The photodiode evaluated the difference in light intensity levels, and the absorption rate was measured through the reflected light detected by the photodiode sensor module, which was then converted into voltages. The detected voltage for each nutrient was compared to threshold values developed by the Arduino microcontroller. This comparison determined the nutrient content deficiency in the soil, categorizing it into three voltage levels: High, Medium, and Low. These values were established based on the absorption rate of each nutrient during the sample measurements.

TABLE II. SOIL SAMPLE SPECIFICATION

Soil sample	Nutrient content
Sample 1	High Nitrogen
Sample 2	High Phosphorus
Sample 3	High Potassium
Sample 4	Low nutrient
Sample 5	Low nutrient
Sample 6	Low nutrient

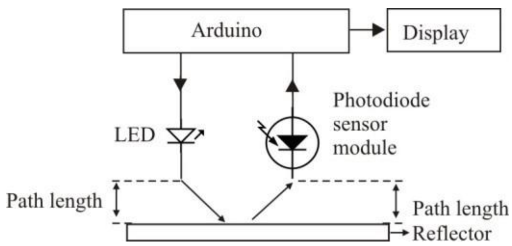

Fig. 3. Schematic diagram of the experimental setup for measuring light path length

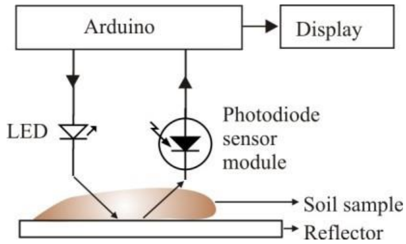

Fig. 4. Schematic diagram of the experimental setup for measuring soil sample

III. RESULTS AND DISCUSSION

Figure 5 illustrates the responses of the photodiode sensor module to LED illumination at various light path lengths, ranging from 1.0 to 4.0 cm. The comparison of these responses aims to identify the optimal path length within this range. As depicted in Fig. 5, the photodiode received the highest amount of UV light at the shortest length of 1 cm. Increasing the path lengths to 2 cm, 3 cm, and 4 cm resulted in a noticeable decrease in the detected voltage values. Based on this analysis and in comparison with other path lengths, the optimal light path length of 1 cm was selected due to its highest light intensity. TABLE III presents the threshold values for NPK soils categorized into three voltage levels: High, Medium, and Low. The value x represents the voltage absorption for each nutrient..

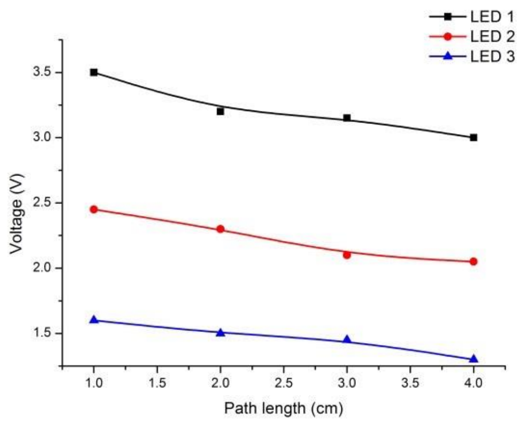

Fig. 5. Determination of optimum light path length

TABLE III. THRESHOLD VALUE FOR LOW, MEDIUM AND HIGH NUTRIENT IN SOIL SAMPLE

Nutrient	Low (V)	Medium (V)	High (V)
Nitrogen	3.5<x<3.8	3.8<x<4.1	x>4.2
Phosphorus	2.45<x<2.8	2.9<x<3.3	x>3.4
Potassium	1.6<x<2.2	2.3<x<2.8	x>2.9

The bar charts in Fig. 6 display the voltage responses from the photodiode when illuminated with light in samples containing Nitrogen (N). Sample 1 exhibited the highest Nitrogen content, exceeding the threshold voltage at 4.51 V. Samples 2, 3, 4, 5, and 6 showed low Nitrogen levels. Sample 2 contained high Phosphorus, while sample 3 had medium levels, specifically at 3.65 V and 3.5 V respectively, as shown in Fig. 7. The threshold value for high Potassium in sample 3 was 3.83 V (Fig. 8). Table 4 summarized the nutrient content in samples 1 through 6 based on the threshold values in Table 3. Thus, the NPK soil content in each sample can be easily determined, indicating specific nutrients that should be applied to enhance each sample's fertility.

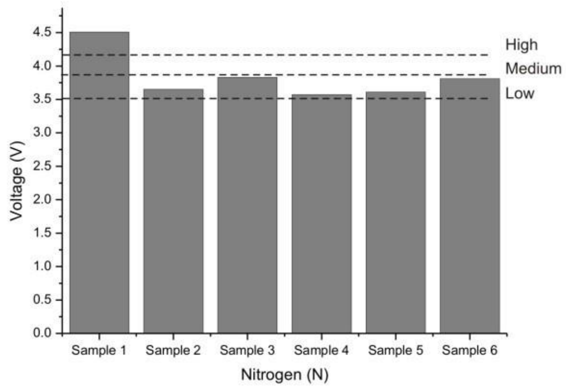

Fig. 6. Voltage responses for different soil samples containing Nitrogen

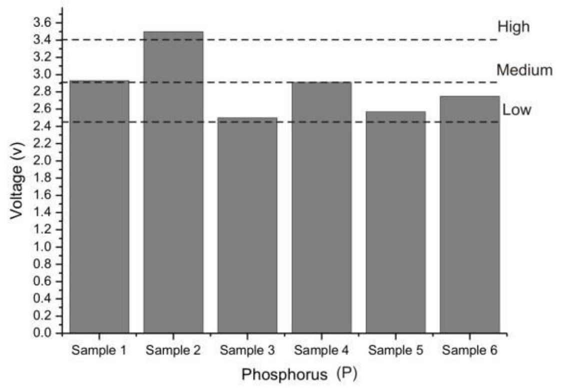

Fig. 7. Voltage responses for different soil samples containing Phosphorus

Fig. 8. Voltage responses for different soil samples containing Potassium

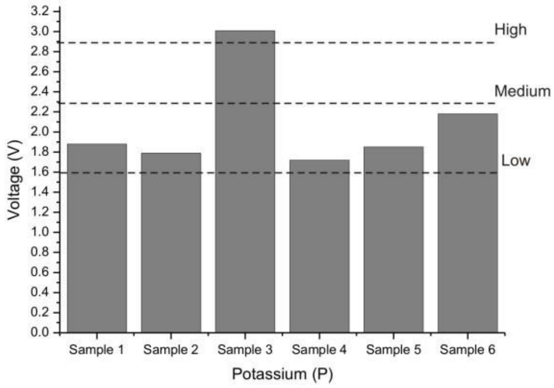

TABLE IV. THE NUTRIENT CONTENT LEVEL IN ALL SAMPLES

Sample	Nitrogen (N)	Phosphorus (P)	Potassium (K)
1	High	Medium	Low
2	Low	High	Low
3	Low	Low	High
4	Low	Low	Low
5	Low	Low	Low
6	Low	Low	Low

IV. CONCLUSIONS

In conclusion, the optical transducer comprising LEDs, a photodiode, and an Arduino microcontroller has been successfully developed and tested as an alternative method for assessing deficiencies in Nitrogen (N), Phosphorus (P), or Potassium (K) in soil. This project offers a cost-effective solution compared to other technologies for determining nutrient levels in soil. It also addresses issues related to excessive fertilizer use, which can lead to plant mortality and reduced crop quality and yield. The optical transducer utilizes light absorption properties of nutrients and establishes threshold values for each nutrient, categorizing their levels into three voltage categories: Low, Medium, and High on the display. According to experimental findings, high levels of NPK nutrients were detected in Sample 1, 2 and 3.

ACKNOWLEDGMENT

The authors gratefully acknowledge Lestari grant (Project Number: 600-IRMI/MYRA 5/3/LESTARI (0156/2016) for the funding. The authors are also thankful to Faculty of Electrical Engineering, UiTM where the research was conducted

REFERENCES

[1] N. Singh and A. Shaligram, "D. NPK Measurement in Soil and Automatic Soil Fertilizer Dispensing Robot," *International Journal of Engineering Research & Technology,* vol. 3, no. 7, pp. 635-637, 2014.

[2] Y. Kulkarni, K. K. Warhade, and S. Bahekar, "Primary nutrients determination in the soil using UV spectroscopy," *International Journal of Emerging Engineering Research and Tecnology,* vol. 2, pp. 198-204, 2014.

[3] D. Q. Huo *et al.*, "Recent Advances on Optical Detection Methods and Techniques for Cell-based Microfluidic Systems," *Chinese Journal of Analytical Chemistry,* vol. 38, no. 9, pp. 1357-1365, 2010.

[4] L. C. Gavade, "Detection of N, P, Kusing Fiber Optic Sensor and PIC Controller," *International Journal of Engineering Science,* vol. 13787, 2017.

[5] D. V. Ramane, S. S. Patil, and A. Shaligram, "Detection Of Npk Nutrients Of Soil Using Fiber Optic Sensor," in *International Journal of Research in Advent Technology (E-ISSN: 2321-9637) Special Issue National Conference "ACGT*, 2015, pp. 13-14.

[6] A. Rashid, "LED Based Soil Spectroscopy," *Buletin Optik 2016,* no. 3, pp. 1-7, 2016.

[7] D. A. Skoog, D. M. West, F. J. Holler, and S. R. Crouch, *Fundamentals of Analytical Chemistry*. Cengage Learning, 2013.