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Integrated optical sensor for NPK Nutrient of Soil detection

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***Abstract*— Soil is the most important medium for plant growth. The aim of this project is to develop a detection system for major nutrients of soil; Nitrogen, Phosphorus and Potassium (NPK) which consists of an optical sensor. The optical sensor is developed with two systems which are transmission system and detection system. The transmission system uses LED powered by Arduino UNO as a component to transmit light directly on the soil which contains nutrients in a transparent container. The detection system utilized two photodiodes developed with signal conditioner and an amplification circuit to detect the intensity of nutrients of the soil through the remaining light and to amplify the signal of light in terms of potential differences. The results show that the absorption response voltage of Nitrogen (N) is 32.0 V, the Phosphorus (P) is 4.6 V and Potassium (K) is 19.8 V. The presence and intensity of these nutrients are detected based on the rate of light absorbed by the nutrients in the soil, which is a high absorption of light by nutrients shows a high intensity of nutrients or vice versa.**

Keywords—NPK nutrient, Optical Sensor, Photodiode, LED, Arduino

I. INTRODUCTION

Nitrogen (N), Phosphorus (P), and Potassium (K) are the major nutrients contained in the soil to provide fertility and support plant growth and reproduce [1-3]. Measurement of the NPK nutrient content found in the soil is necessary to determine the additional fertilizer quantities to be added as additional nutrients to improve soil fertility [4]. The farmers who are not exposed to modern technology still using traditional ways to increase the quantity of plant food on their harvests. Besides that, the technology in the market is expensive, heavy and it is hard to apply for less knowledgeable farmers is the reason why farmers are even practicing the manual way to feed their plants.

In this era, there is a method used by farmers to improve their crop quality which is precision agriculture, the concept of farming management to fertilizer monitoring of lack or excess of nutrients. It is carried out by collecting soil samples from plantations and transported to laboratories for analysis of nutrient present in the soil and the process is conducted for one or two weeks to obtain the results [5]. Nevertheless, this technique requires a long time, requires high cost and variables affecting crop yields cannot be varied and optimized in real time. Due to the lack of this system, analysis of nutrient concentrations in the soil cannot be well defined.

Previous works have been reported to detect nutrient of soil, such as using optical methods. This technique is carried out through the principle of interaction between light and nutrient due to the physical and chemical levels of the soil. When a sample was illuminated with light, certain bonds within the molecules vibrate with the varying electric field, and the vibration bonds absorbed optical energy and caused less light to be reflected off the sample [6]. A multimode plastic fiber optic sensor is developed that consist of seven fibers arranged in a concentric configuration acting as receiving fiber and six fibers as transmitting fibers which are part of a sensor probe used to detect the most powerful nutrients in soil [7]. The detection system is improved by removing the usage of fiber optic and replaced with a direct detection method using various types of light sources and detectors. Kulkarni et al. utilizing a tungsten lamp in UV spectroscopy based in the determination of primary nutrients [8]. While Wang et al. proposed the detection of nutrients in VIR/NIR region [9]. The combination of LED as a light source and photodiode as a detector is constructed as a spectroscopy for direct detection of NPK nutrient of soil. The wavelength range used for the light source is from 400 nm to 1200 nm due to absorbance level for organic soil was found within this range. Nitrogen has a strong light absorption from 450 nm to 540 nm, Phosphorus at 800 nm and 970 nm and Potassium absorb more light at around 620 nm [10-12].

Thus, the aim of this research is to develop an integrated optical sensor for NPK nutrient of soil detection. It consists of a transmission system based on LED to transmit light directly to the soil and a detection system based on photodiode to receive light as to improve the optical sensor techniques in determining nutrient concentration values in soil samples. This principle used to detect the nutrients contained in the soil by using photodiodes that function to detect light from the LEDs that are absorbed by the soil. Photodiode detection of the remaining light is a method for specifying the absorption of a nutrient in the soil. The wavelength of the LED is chosen depending on the wavelength of the NPK nutrients [10, 11]. The system does not require a high cost and low power consumption to power up the LEDs and photodiode is developed with a precise signal conditioning circuit.

II. Methodology

The schematic diagram of the integrated optical sensor with the vertical construction of light transmitting system and light detection system is presented in Fig. 1. It consists of two LEDs as a light source while a photodiode as a detector incorporating a signal conditioning circuit and a transparent container made of PET (Polyethylene Terephthalate). Arduino is employed to generate a square wave signal in order to monitor the operation of the LED such as controlling the frequency, sequences and the duration of the light emission. The LED wavelength used to detect the nutrients are LED N (470 nm) for Nitrogen, LED P (950 nm) for Phosphorus and LED K (660 nm) for Potassium .

The light signal from the LED is emitted with frequency modulation at 1 kHz and duty cycle at 45 %. As the light travels along with the transparent container, the luminosity is directly interacting with the nutrient sample. The remaining light resulting from the absorption of nutrients is received by the Si photodiode with peak wavelength of 850 nm and converted into a photocurrent. The observed value is normally in the rate of few nanoamperes and the signal conditioning is developed to convert the signal to a proportional voltage. The signal conditioning circuit consists of low pass filter to pass the 1 kHz modulation frequency and high pass filter to block the noise frequency normally at 120 Hz. The output signals are then displayed on an oscilloscope.

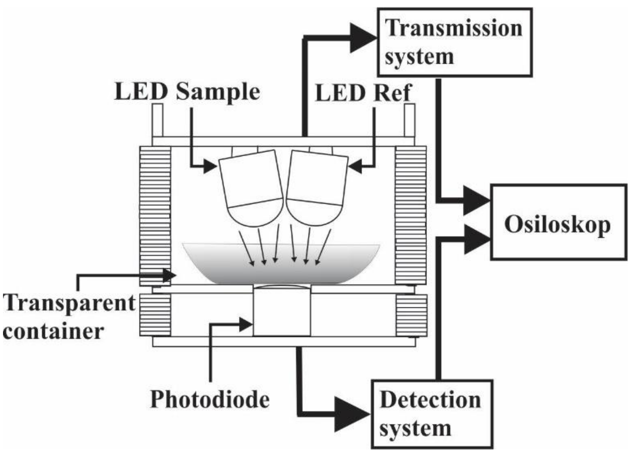

Fig. 1. Schematic diagram of vertical construction of NPK nutrient of soil optical sensor

A. *Working Principle*

To determine the concentration level of a nutrient, the Beer-Lambert Law equation is used. There is a linear relationship between absorbance and concentration of an absorbing species [13]. Light from the LED is emitted toward the transparent container contain the soil sample, the incident light is scattered and absorbed by the nutrient, reducing the intensity of the transmitted light. The equation of the absorbance as shown in Eq. (1) where I_1 is transmitted light and I_0 is incident light.

$$A = -\log_{10}\left(\frac{I_I}{I_o}\right) \tag{1}$$

B. *Testing Procedures*

The optimization of the integrated optical sensor is performed by varying the distance between the LED and photodiode in order to determine an optimum optical path length. This appropriate distance selection is determined based on the results of a good response signal. The optimum optical path length can be determined by testing in five distance positions between LEDs and photodiodes. The recorded data is in voltage peak-peak (V_{pp}). The distance starts from 15 mm to 20 mm. This is due the voltage response decreasing when it reach 20 mm.

The soil samples used to test the presence of the concentration of NPK nutrients in the soil in this testing is listed in Table I. The six samples were taken according to their location and characteristic. Two soil samples were taken from a residential area, another two soil samples were from a college area and followed by another two samples from the lake area. Before the soil testing was conducted, the optical transmittance was measured by emitting each NPK LED through the PET transparent container without any sample as depicted in Fig. 1. This was to ensure the amount of light received by the detection system was higher so the precise absorption rate can be achieved. Wang et al, has verified optical transmittance through PET material is around 85 % within the spectra range from 400 nm to 1200 nm [14]. To verify all the sample, the water need to be mixed with the soils for the nutrient sample solutions and place inside the transparent container using similar setting shown in Fig. 1. Each sample output response was observed and recorded using the oscilloscope.

TABLE I. LIST OF SAMPLES

Sample	Location	Soil's Characteristics
1	Residential area	Dry and sandy
2		
3	College area	Dry and grassy
4		
5	Lake area	Grassy and damp
6		

III. Results and Discussion

Fig. 2 shows the constructed optical sensor for NPK nutrient of soil detection, including light transmission and detection system. The vertical distance of the LED can be adjusted from 15 to 20 mm in order to ascertain the optimal path length of the light. The resulting signals for each tested distance are recorded to choose the optimum path length. Based on the results of Fig. 3, shows that the increasing length from 15 mm to 20 mm, the value of all the voltage signal start to decrease. Therefore, the optimum light path length of 15 mm is the optimum length and was preferred due to the higher intensity of light in voltage.

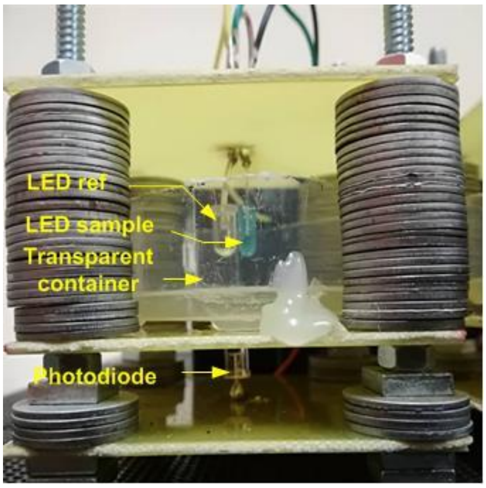

Fig. 2. Vertical construction of NPK nutrient of soil optical sensor

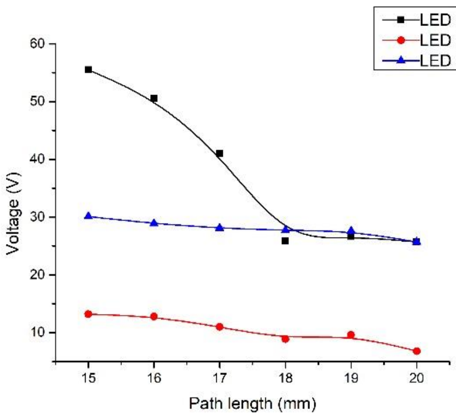

Fig. 3. Determination of the optimum optical path length.

The square wave signal with modulation frequency at ≈ 1 kHz generated by the LED driven by an Arduino on channel 1 and 2 shown in Fig. 4 and Fig. 5 respectively. The LED was pulsed ON at a duty cycle of 45 %. The photodiode voltage responses at similar frequency, from the amplification circuit are depicted in channel 3 (both figures). The output voltage response is due to the light illuminating from the LED through the transparent container. The transparent container used for sample testing is made of PET (Polyethylene Terephthalate) which allows approximately 85% of light from LED N, P and K through the medium. Based on the testing results, all LED lights have a high optical transmittance approximately at 80% as indicated in Fig. 6.

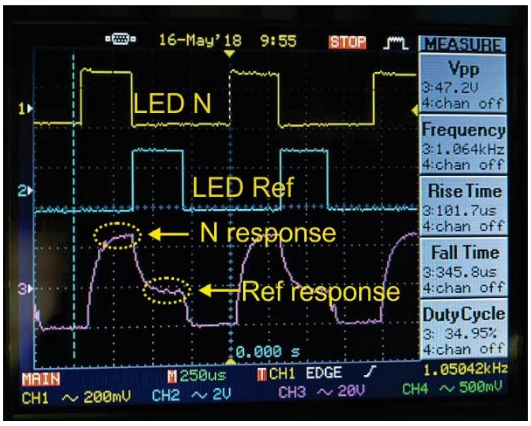

Fig. 4. LED N and LED Ref and photodiode signal responses without sample

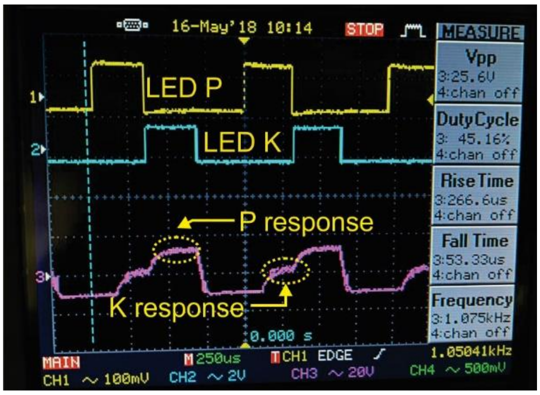

Fig. 5. LED P and LED K and photodiode signal responses without sample

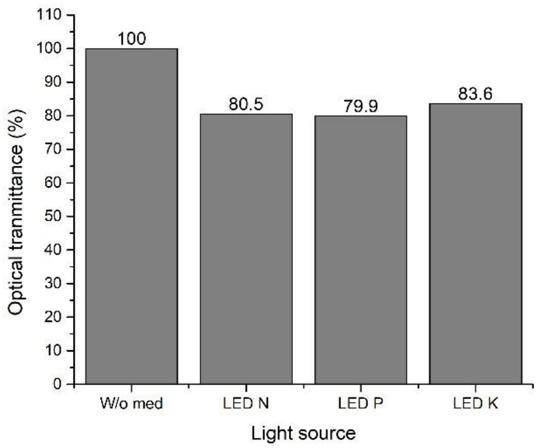

Fig. 6. Optical transmittance of LED NPK

The bar chart in Fig. 7 shows the voltage responses from the photodiode due to light illuminates to the 6 soil samples contain Nitrogen, Phosphorus and Potassium. The light illumination without a sample is also included as a reference. The voltage reference for Nitrogen, Phosphorus and Nitrogen is 47.2 V, 11.2 V and 25.6 V respectively. The highest amount of Nitrogen contained in sample 5 as the voltage value decreases at 32 V due to light absorption. Sample 2 and 4 contain low of Nitrogen as the voltage value decrease is small. Sample 3 contains high of Phosphorus, while low in sample 6 which is at 5.6 V and 11.0 V respectively as illustrated in Fig. 7. The high amount of Potassium in sample 4 which is 19.8 V while the lower amount is found at sample 5 with output voltage of 24.8 V. Therefore, the NPK soil content in each sample can be easily determined with only particular nutrient should be dispensed to the sample.

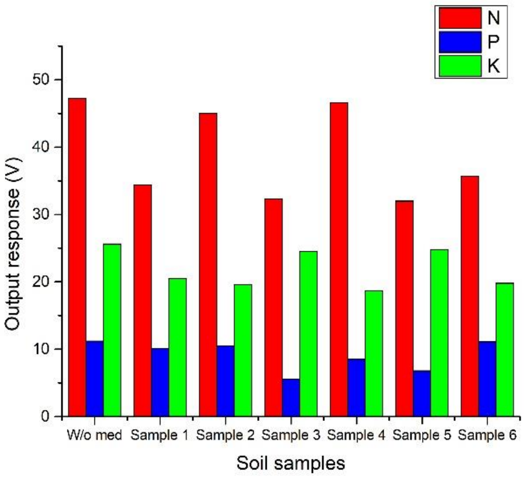

Fig. 7. Output responses for NPK soil samples

IV. Conclusion

The developed integrated optical sensor was able to detect the NPK nutrients in soils. The light for LED at 470 nm, 950 nm and 660 nm emitted at 1 kHz modulation frequency was successfully received by detection system within 15 mm optical path length. The optical transmittance of each LED light through the transparent container is high, approximately at 80 %. Based on the testing results, there was a significant interaction between the light and NPK samples taken from different location that made the light intensity reduced as the voltages were dropped. The output responses for high NPK were found at 32.0 volts for Nitrogen, 4.6 V for Phosphorus and 19.8 V for Potassium.

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