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Relationship Light Absorption-Based Sensor for Detecting Oil Pollution

Nur Nazifa Che Samsuria, Wan Zakiah Wan Ismail, Mior Fakhrul Hazim Mior Abdul Halil, Irneza Ismail, Farah Masyitah Mohd Shuib

[1] Advanced Devices and Systems, Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, Nilai, Negeri Sembilan, Malaysia

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ABSTRACT

Oil pollution can destroy nature, aquatic life and crops. A simple approach for detecting oil pollution was developed using photodiode, microcontroller and light-emitting diode (LED). Our system was developed based on light absorption where the intensity of light that passed through a slick of oil was measured to detect the presence of oil in water. The analog value (intensity of light) from photodiode was converted to resistance value for further data processing. Experimental setup was conducted by varying distances (6 cm to 9 cm) from light source to photodiode, varying volumes (50 ml to 200 ml) and varying exposure time (1-6 hours). As the oil volumes increased, the average resistance values decreased. The system can be tested in irrigation canals, lakes or reservoirs used in agriculture. The system has the potential to assist farmers to detect oil pollution as a preliminary precaution before harming the plants.

1. Introduction

Oil pollution in irrigation canals, lakes or reservoirs can pose significant risks to the environment and agriculture. Contamination of soil and water can harm crops, leading to economic losses for farmers [1]. If oil pollution occurs near farmland, the soil and water can become contaminated, leading to crop damage and reduced yields. These issues can have major impacts on the financial stability of farmers, as well as on the local economy. In addition, oil pollution can also harm livestock, further reducing the income of farmers. Thus, many methods have been developed to monitor soil and water comprising of electronics [2-4] and optical methods [5-7].

Traditionally, oil pollution detection in water and soil has relied on manual inspection and the use of absorbent materials to absorb and contain the pollution. However, these methods are labor-intensive and may not be practical or effective in all situations. Basterrechea *et al.* [8] used an optical method to monitor the discharge of industrial oil in irrigation ditches. The optical method depends on light absorption theory [9] that is measured by comparing the intensity of the light as it enters the sample, I_o with the intensity of light as it leaves the samples, I. Mathematically, the light absorption, A is expressed as:

$$A = \log (I_o / I) \tag{1}$$

Oil concentration in water samples can be estimated using optical sensors, which can identify and measure the light absorption by oil-containing compounds [10].

Previous methods of detecting and monitoring oil consist of real time monitoring, optical sensing, and surface plasmon resonance [5,8,11]. Tehrani *et al.* [11] integrated the optical images with machine learning approach to detect oil pollution in the Persian Gulf whereas Yin *et al*. [5] developed the detection and monitoring of oil pollution based on surface plasmon resonance. Most of the previous methods used high-cost equipment and were suitable for large margin sectors. Basterrechea *et al.* [8] used optical sensor to monitor oil pollution in irrigation ditches. Different types of LEDs were used to identify the source of oil.

Thus, the aim of this research is to develop a system that can be used to detect the presence of oil in irrigation canals, lakes or rivers which can help to prevent contamination of soil and water sources. The system consists of a light source to shine the oil-water substance and a detector to detect the intensity of light as it leaves the substance. When light is shined through the substance, the intensity of the light that passes through will be reduced by the presence of any substances that absorb light, such as oil. Here, a buoy was applied that acted as a floating platform that contained sensors and monitoring equipment, allowing for the transmission and gathering of data. To keep track of the buoy's movement, it can be strategically placed in water bodies, including irrigation canals, lakes or rivers. As an early warning of contamination, the photodiode installed on the buoy can identify changes in light intensity due to the presence of oil. The usage of buoys in oil pollution detection are affordable and scalable depending on area, volumes and types of applications [12,13]. This research is useful for farmers to detect oil pollution earlier and allowing for quicker action to be taken. This can help to minimize the spread of pollution and limit its impact on farmland and livestock.

2. Methodology

In this research, the ESP32 was chosen as the microcontroller of processing power and communication capabilities, to interface with optical sensor. A blue LED was chosen to be the light source since a previous study [14] showed that the blue LED was able to produce the maximum variation of light intensity compared to other colour LEDs. Then, a photodiode (LM393) acted as the light sensor or detector to capture changes in light intensity. The photodiode was chosen since it was sensitive to light, can detect low light level and suitable to measure the light intensity. Engine oil was used as the oil sample.

2.1 Circuit Connection

Fig. 1 shows the design of the circuit that consists of ESP32, a blue LED as the light source and a LM393 photodiode as the sensor to measure the intensity of the transmitted light.

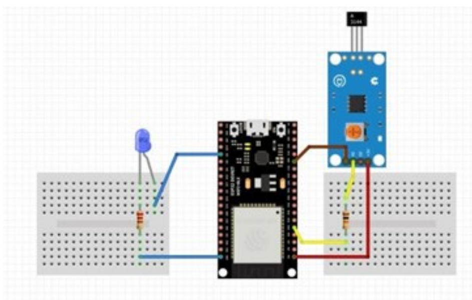

Fig. 1. Circuit design that consists of ESP 32, LED and photodiode

The ESP32 is a compact, low-power microcontroller module designed for Internet of Things (IoT) applications since it has integrated Wi-Fi module and Bluetooth. The blue LED and the photodiode can be directly connected to the ESP32 for the system. To avoid the damage to the component due to excessive current, resistors are connected in series with them.

2.2 Development of The System

Arduino IDE software was used with the ESP32 microcontroller. The ESP32 provides processing power and memory, processing data and communication capabilities like Wi-Fi and Bluetooth. The analog-to-digital converter (ADC) in ESP32 is also important since it is useful for converting the analog signal into digital format for further analysis.

Fig. 2 shows schematic diagram of the circuit. The coding is then uploaded using Integrated development environment (IDE) software before the system can start functioning.

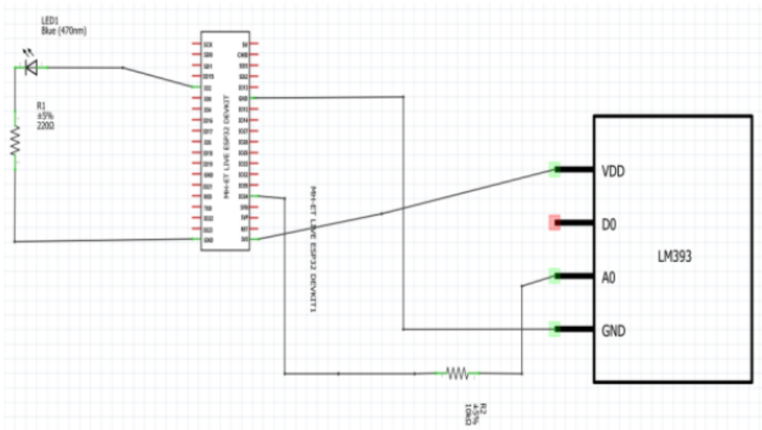

Fig. 2. Schematic diagram of the circuit for the system

2.3 System Design

Fig. 3 shows a floating buoy that was designed in Tinker AD, an online 3D modeling program where the distance between the LED and the photodiode were adjustable. Four rods supported the buoys that were parallel to each other, and two different platforms were used to link the rods together. Other components such as a trio of floaters, a waterproof light casing and a water resistance box were designed as well. The casing was used to place the ESP32 module and the photodiode. Then, the blue LED was placed in the middle of the bottom platform where it beamed its light upwards to the photodiode that placed at the upper platform.

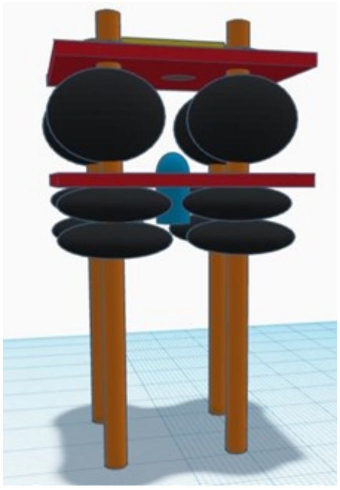

Fig. 3. Buoy design and the placement of blue LED

2.4 Operation of The System

Firstly, the system measured the transmitted light from the light source to the detector through the oil in water. After that, the light intensity was converted to voltage value by using ADC formula [15]. Then, the resistance value was calculated by using voltage divider rule (VDR) formula. Based on previous study, there was oil presence in the water when the resistance value was lower than 18 kΩ [8]. Photodiode measured the intensity of light and was converted into voltage values that the microcontroller could process. The measured analog signal value refers to the amount of light that the optical sensor can detect. The number of discrete levels or steps that the ADC can represent refer to the resolution. To convert the measured light intensity to a voltage value, V, the ADC formula divides the measured signal value by the maximum possible value represented by the ADC resolution as shown in (2). The ESP32 has 12-bit ADCs [16] and the ADC resolution is 2^{12} = 4096 steps. Thus, the steps vary from 0 to 4095 where the maximum number of the ADC resolution, Res is 4095.

$$V = (I_o / Res) \times V_s \tag{2}$$

where I_o refers to light intensity, Res is the resolution of ADC and Vs is the system voltage for the ESP32 (3.3V).

The data can be further analyzed by determining the resistance value using the VDR formula after obtaining the voltage value via the ADC conversion. Then, the resistance can be calculated using the VDR formula [17] based on the measured voltage and the circuit's known characteristics. In this project, a voltage divider circuit made up of the measured voltage (V) and known resistances is subjected to the VDR formula. Generally, a series connection of a known resistance (R_2) and an unknown resistance (R_1) are used to build the voltage divider circuit. The voltage that being measured is applied across an unidentified resistance (V_{out}). The VDR formula is expressed as in:

$$V_{out} = \{R_2 / (R_1 + R_2)\} \times V_s \tag{3}$$

where, V_{out} is the calculated voltage, R_2 is the resistor connected in series with photodiode (10 kΩ) and V_s is the system voltage for ESP32 (3.3V). By rearranging (3), the unknown resistance (R_1) can be solved as in:

$$R_1 = \{(V_s \times R_2) / V_{out}\} - R_2 \tag{4}$$

Resistance value provides a direct measure of the presence of oil in water samples. By calibrating the system with known resistance values, a relationship between the resistance and the oil presence can be established. Using the low-cost optical sensor and ESP32 microcontroller combination, oil in water can be detected by identifying and categorizing oil pollution based on the observed resistance values.

2.5 Experimental Setup

A testing experiment was set up to determine the resistance values for water with and without oil, various distances from the light source to the sensor, various oil volumes and increasing exposure time. The configuration ensures reliable measurements of oil pollution detection.

The experiment was started by using water sample (Cuckoo) without oil. A glass tank (30 cm × 20 cm) was used to store the water sample. Next, the light source and the photodiode were positioned on the buoy. The system was then powered on by a power bank, and the intensity of the transmitted light was measured using the photodiode for 6 hours. This measurement served as the baseline for the resistance value of the water without oil.

The experiment was continued by varying the volume of engine oil in the water. Volumes of oil varied from 50 ml to 200ml to study the effect of oil volumes on light absorption of engine oil. Throughout the experiment, 3 liters of water was used, and the experiment was repeated 3 times.

3. Results and Discussion

3.1 Physical Appearance of Oil in Water

The Fig. 4 shows the physical appearance of oil in water before the experiment was started and Fig. 5 shows the physical appearance of oil after three days in water.

Fig. 4. Physical appearance of oil in water before experiment was conducted

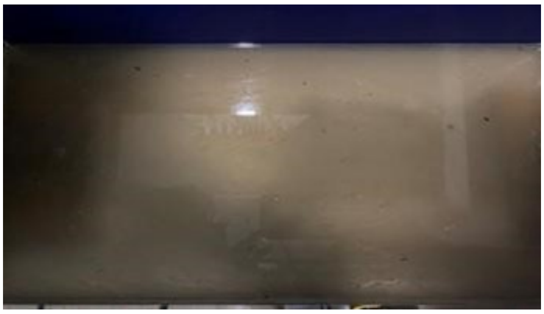

Fig. 5. Physical appearance of oil in water after 3 days

3.2 Resistance Values for Water Without Oil

Table 1 shows that the resistance ranges from 34kΩ to 48kΩ in 6 hours. The resistance values for water without oil, obtained throughout 6 hours period (Table 1) serve as a reference for the system. The resistance values of water without oil will be compared with the resistance values of water with engine oil.

Table 1
Average Resistance Value for Water Without Oil

Hour	Resistance (Ohm)
1	344585.2453
2	290070.6244
3	372281.5776
4	478847.0218
5	427498.6022
6	362147.2014
Average	**379238.3788**

3.3 System Performance in Terms of Distance

Fig 6 shows the resistance values of oil in water for various distances from light source to photodiode within six hours period.

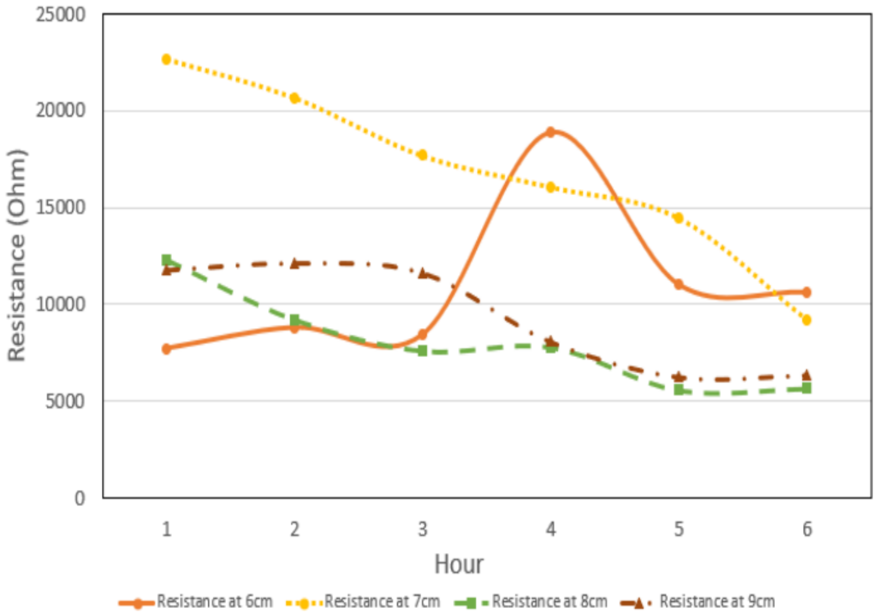

Fig. 6. Resistance values of oil in water for various distances from light source to photodiode

At 6 cm, the minimum resistance value is 6 kΩ at the first hour and the highest resistance value is 18.8 kΩ at the fourth hour before the values drop to 12kΩ at the fifth hour. At 7 cm, the resistance values are considerably higher compared to the other distances throughout six hours period. The resistance values decrease gradually within 6 hours. At 8 cm, the resistance values also show a decreasing trend over time. Lastly, at 9 cm, the resistance values display a slight fluctuation but generally remain consistent over the six-hour period. Overall, we observe a similar pattern where it starts with a low resistance value at 6 cm, then spikes at 7 cm for almost overall exposure time except at the fourth hour and at the sixth hour. Then, the resistance values decrease for 8 cm distance and the pattern is also similar for 9 cm distance.

3.4 System Performance in Terms of Exposure Time

Fig 7 shows the resistance values fluctuate when the volume of oil increases from the first hour to the fifth hour. Meanwhile, at the sixth hour, the resistance values reduce gradually when the volume of oil increases. Resistance measurements for the 50 ml volume show a high initial value at the first hour (17.4 kΩ), and the measurement fluctuates with time. It also shows that exposure time can affect the resistance values. We attribute this condition to the dispersion and dissolution of oil in the water. As time increases, the resistance values reduce showing the physical appearance of oil in water changes over time.

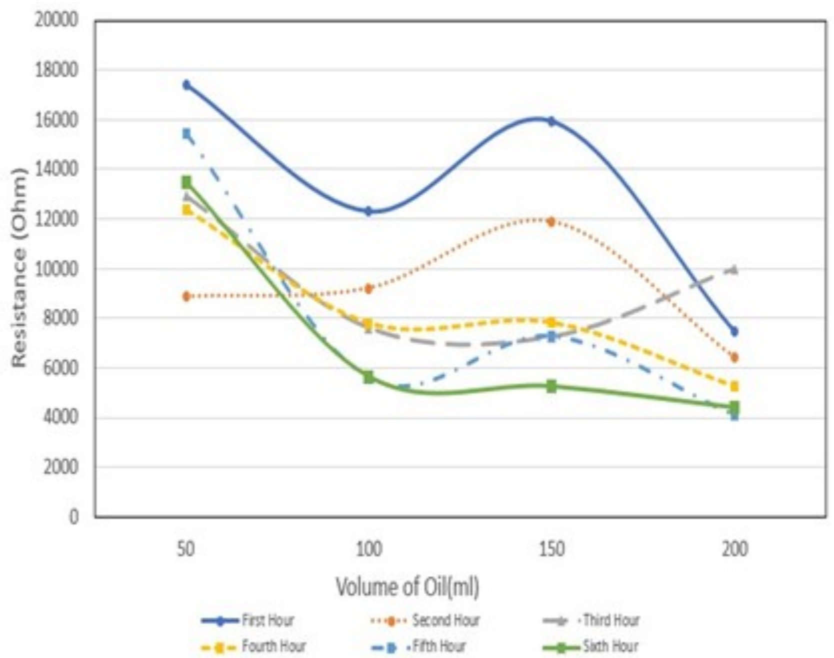

Fig. 7. Resistance values for various oil volumes in water

Then, the initial increase in resistance is due to the formation of a layer of oil droplets on the surface of the water. As the oil droplets disperse in the water and oil particles interact with water, the resistance of the sensor starts to decrease [19].

3.5 System Performance in Terms of Oil Volumes

Fig. 8 shows the resistance values in terms of exposure time for each volume of oil. The figure provides insights into the behavior of resistance over time for various volumes of oil. Resistance values for 50 ml and 200 ml of oil fluctuate while the resistance values for 100 ml and 150 ml of oil decrease throughout the experiment for six hours. For the 50 ml of oil volume, the resistance value starts at a high level, 18kΩ at the first hour and fluctuates before it reaches the lowest value, 5.6kΩ at the sixth hour whereas for 200 ml of oil volume, the resistance value is 7.8kΩ at the first hour, reaches 10kΩ at the third hour and decreases back to 4kΩ at the sixth hour. For the volume of 100ml, the resistance values start at a relatively high level (12kΩ) and decrease to 6kΩ at the sixth hour. This indicates that the presence of oil in the water affects the absorbed light, leading to a decrease in resistance values. In a six hours period, the 200 ml of oil volume shows the lowest resistance values, indicating that higher oil volume prevents more light from reaching the photodiode. There are variations in the resistance values from hour to hour, indicating changes in the interaction between the oil and the transmitted light. Overall, as the experiment went on to 6 hours, the resistance value decreased because the oil molecule interacts with water leading to cloudy water.

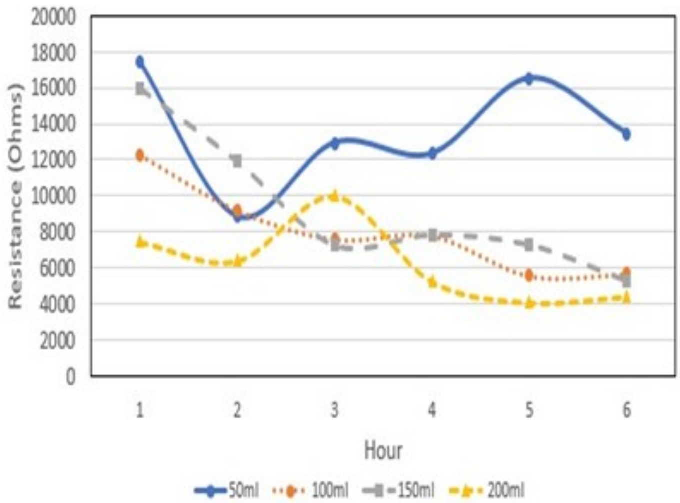

Fig. 8. Resistance values in terms of exposure time for 8 cm distance

4. Conclusions

In conclusion, the research aims to study the oil pollution detection in water based on light absorption. The system consisted of photodiode, LED and ESP32 microcontroller, installed on a buoy. The system was tested based on oil volumes, distance from light source to photodiode and exposure time, The study shows that the increasing distance between the LED and the photodiode can decrease the resistance value. Higher volume of oil also affects the resistance value of the system. The effective development of this system creates opportunities for additional study and advancements in environmental monitoring and oil pollution detection technology. In future, the light detection and ranging (LIDAR) will be applied to detect oil pollution and the study will involve many types of oil pollution in river and ocean.

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