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Detection of Oil in Water Using Photodiode and Internet of Things

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Oil detection, light sensor, real time monitoring

Abstract

Oil spills in irrigation ditches can have severe environmental and agricultural consequences. We proposes a system that can detect oil spill using a photodiode and an Internet of Things (IoT) platform to enable real-time monitoring. The system integrates a blue light-emitting diode (LED), a photodiode, and an ESP32 microcontroller, which measures resistance changes as an indicator of oil presence in water. Experimental evaluations were conducted by varying the distance between the light source and sensor (6 cm to 9 cm), oil volume (50 mL to 200 mL), and exposure time (1-6 hours). Results indicate that resistance values for oil-free water range from 300 kΩ to 500 kΩ, while oil-contaminated water consistently exhibits resistance below 18 kΩ. The optimal distance for accurate oil detection was determined to be 8 cm, maintaining stable resistance values. Increasing oil volume and prolonged exposure time reduced light penetration, causing a decrease in resistance. Real-time monitoring via the Blynk application provides immediate alerts when oil is detected. The proposed system offers a low-cost, efficient, and scalable solution for early oil spill detection in agricultural irrigation systems, minimizing environmental damage and improving water quality management.

1. Introduction

The use of new technologies may have negative effects on the environment. Some industries may illegally dump oil into water that is used for agriculture activities. The polluted water has the potential to contaminate the soil, groundwater and other water sources. Farmers usually use groundwater and irrigation ditches as the water source for crops [1]. The basic goal of irrigation systems is to use the least amount of water to water the plants and lawns. Irrigation avoids soil compaction, suppresses weed growth in grain fields, and shields plants from cold. Installing an irrigation system will aid in water conservation, save time and money, stop weed development, and speed up the growth of lawns, plants, and crops [2]. Meanwhile, oil that is combined with soil can change the physical, biological and chemical properties of the soil [3], [4]. Oil in soil can cause physical changes such as particle clumping, which limits water penetration and affects porosity. Oil introduces hydrophobic chemicals which change nutrient availability and potentially impact pH and nutrient balance. Currently, irrigation is mostly used for cultivation of paddy and plays a small role in cultivating cash crops. In major paddy cultivation in Malaysia, farmers choose the flooding type to control the water depth [5]. The oil can coat crops preventing them from receiving sunlight and wilt the crops which eventually leading to death [6]. Thus, monitoring water and soil is important in agriculture where it can be done using electronics [7], [8], [9] and optical methods [10], [11], [12].

Korshunova et al. [13] suggested novel strains of herbicide-resistant hydrocarbon-oxidizing Pseudomonas bacteria from oil-contaminated agricultural soils. The identified strains, alongside their herbicide resistance and oil-degrading capacities, were also considered to enhance the establishment and development of phytomeliorant plants. The outcomes of these trials can be utilized to examine the interactions between microbes and plants in instances of complex oil and herbicide contamination, as well as to formulate strategies for the remediation and restoration of such anthropogenically affected regions.

Previous techniques of detecting oil spills consist of a low-cost system utilizing optical sensors [10], [14], [15], [16], [17]. Tehrani et al. [14] combines machine learning approaches and optical images for oil spill detection. Other previous techniques use optical sensors with LEDs and photodetectors for efficient oil detection. This method employs optical sensors and can detect oil even at concentrations as low as 0.1%. The installation process is straightforward, user-friendly and the system is cost-effective, but the system cannot give real-time monitoring [15], [16]. If the resistance value of light dependent resistor (LDR) is lower than 18kΩ, oil pollution is considered [15]. Fiber-optics surface plasmon resonance sensors are also used for real-time detecting and monitoring oil spills [10]. The system involves fiber-optic sensors that gauge the surface plasmon resonance of light as it reflects off oil slick. It provides real-time monitoring and accurate measurement, but the system is complex and expensive, suitable for large margin sectors such as Oil and Gas companies. Most of the previous techniques use complex algorithms and processes since the methods require multiple processing steps and algorithms for detection. It can be hard and difficult for end users like farmers.

Therefore, a simple oil spill detection and monitoring system needs to be done to detect any oil spills in irrigation ditches earlier since the spills can damage the crops. Here, we have developed an oil spill sensor system where the transmitter can send out a light beam that propagates through the water-oil medium and the light is detected by a photodiode. The photodiode measures the light in analog value and then converts it into resistance value. The innovative approach is proposed to tackle the issue of oil spill pollution in irrigation ditches through the integration of optical sensors with an Internet of Things (IoT) platform. Traditional methods of monitoring and detection are often inefficient, labor-intensive, and may overlook small oil discharges, leading to significant ecological and economic repercussions. Overall, optical sensors and IoT can offer a reliable and efficient way to detect oil pollution for environment sustainability.

In short, the study is structured as follows; methodology, experimental set up, results and discussion and conclusion. The methodology section explains both theoretical and conceptual framework, followed by an explanation of sample preparation procedures, specifically focusing on engine oil. The study explores the development of a low-cost oil spill detection system utilizing an optical sensor integrated with IoT technology, including the design of a buoy and the operational aspects of the detection system, culminating in a thorough description of the experimental setup. Subsequently, the next section comprises results and discussion on system's performance for many samples such as water without oil, various distances of the LED source to detector, different volumes of oil and real-time monitoring capabilities facilitated by the Blynk platform. Finally, the conclusion summarizes the findings and implications drawn from the research.

2. Materials and Methods

The methodology section explains the theoretical and conceptual framework based on light propagation theory, sample preparation, the development and operation of low-cost oil spill detection using optical sensor with IoT and the buoy design.

2.1 Theoretical and Conceptual Framework

The theoretical framework is based on light propagation theory which involves light absorbance, transmittance, and reflectance [18]. Fig. 1 shows the propagation of light from water to oil medium. Incident light is a light source such as laser or light emitting diode (LED) that shines in the medium. Light can be absorbed by oil molecules and the transmitted light from the oil medium can be measured by a detector. The framework considers the relationship between light intensity and optical properties of the oil, such as its absorption spectrum, refractive index, and scattering characteristics. In this study, a light source (blue LED) and a photodiode are used to illuminate water in the ditch and to measure the amount of light that propagates through the water-oil medium respectively. The wavelength of blue LED is 450nm-500nm [19]. The blue LED is applied since blue-light absorption and the oil thickness has high correlation. The blue LED is used to illuminate water in the ditch. Blue light interacts more strongly with certain oil components, enhancing the accuracy of measurements. This is because blue light, having a shorter wavelength and higher energy, is more susceptible to scattering and absorption by specific chemical bonds found in oils.

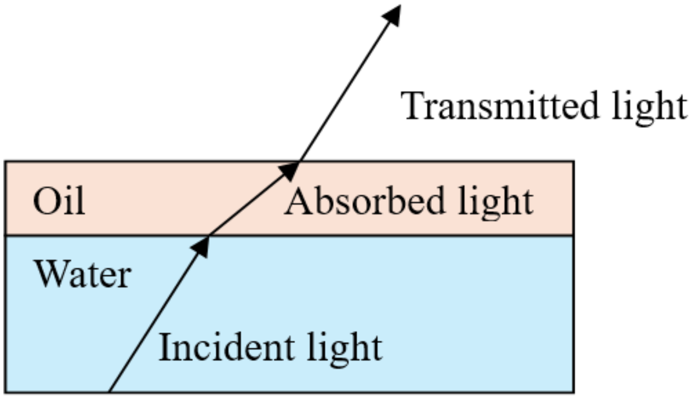


Fig. 1 *Incident and transmitted light with water-oil interface* [20]

The conceptual framework describes the integration of optical sensor with Internet of Thing (IoT) technology for real-time monitoring and data transfer. It employs a blue LED as the light source and a photodiode to measure the intensity of light transmitted through the sample that consists of water with oil slick. After obtaining the light intensity, the resistance value can be measured based on Voltage Divider Rule (VDR). The photodiode shows analog value for the light intensity which is converted to voltage through Analog-to-Digital Converter (ADC). Given the known resistance value that is connected to the photodiode is 10 kΩ, the series resistance value can be determined through VDR to analyze further the presence of oil in water. The ESP32 microcontroller is applied to facilitate data gathering, processing, and connectivity with IoT systems. The conceptual framework also includes the IoT architecture, which consists of data transmission protocols, cloud-based platforms for data storage and visualization, and user interfaces for real-time monitoring and alarm systems.

2.2 Sample Preparation (Engine Oil)

Engine oil is used in the experiment. The type of engine oil is Shell Helix Ultra 5W-40 Fully Synthetic Motor Oil, made from natural gas, diesel and gasoline engines. The oil waste can be found in the irrigation ditches due to leaking from old farm machine or mishandling of the machine. Engine oil is a common oil in industrial and transportation sectors [15], making it an appropriate choice to evaluate the performance of the system in detecting and quantifying oil presence in irrigation ditches. The use of motor oil allows the system's sensitivity and accuracy to recognize and separate oil spills from other pollutants. By using engine oil as the oil spill substance, this study intends to give insight into the effectiveness and practicality of the developed system in the real-world scenarios.

2.3 Developing Low-Cost Oil Spill Detection Using Optical Sensor with IoT

The system uses ESP32 development kit [21], LM393 photodiode [22], blue LED and resistors. The blue LED is chosen since the blue-light absorption is highly correlated with the oil where maximum variation of light intensity can be observed when blue LED is used [16], [23], [24]. Fig. 2 shows the system development and Fig. 3 depicts the schematic diagram of the developed system, sketched using fritzing software.

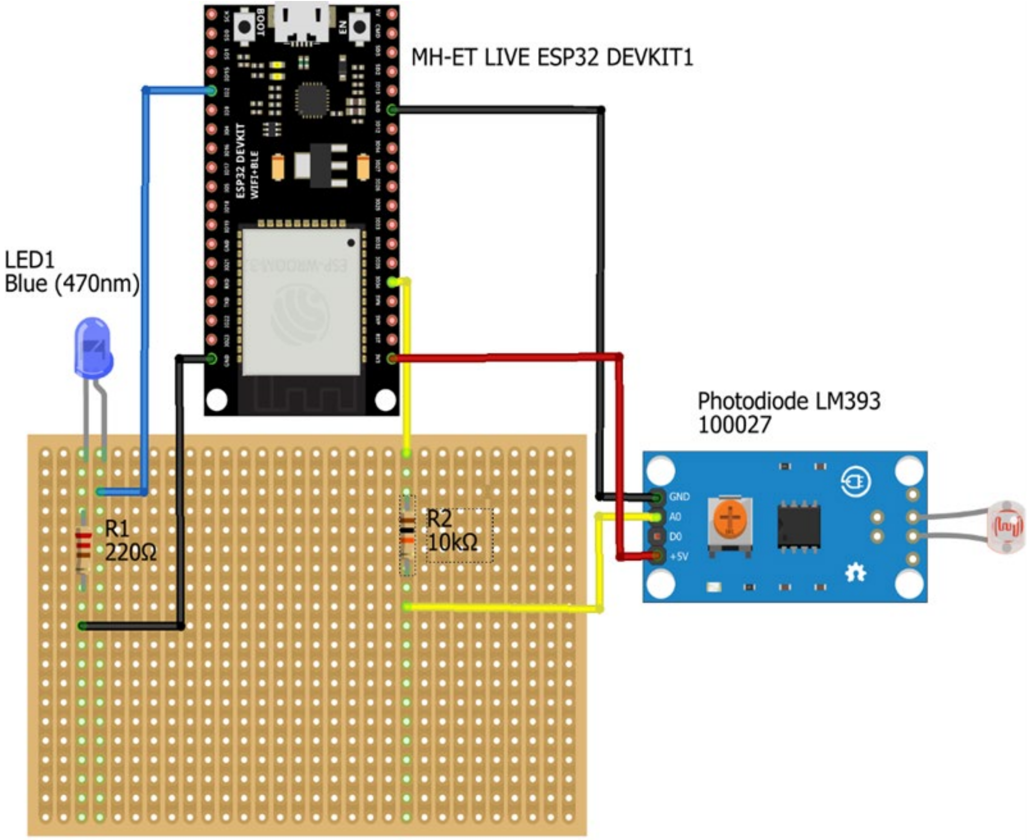


Fig. 2 *Circuit diagram of the system development*

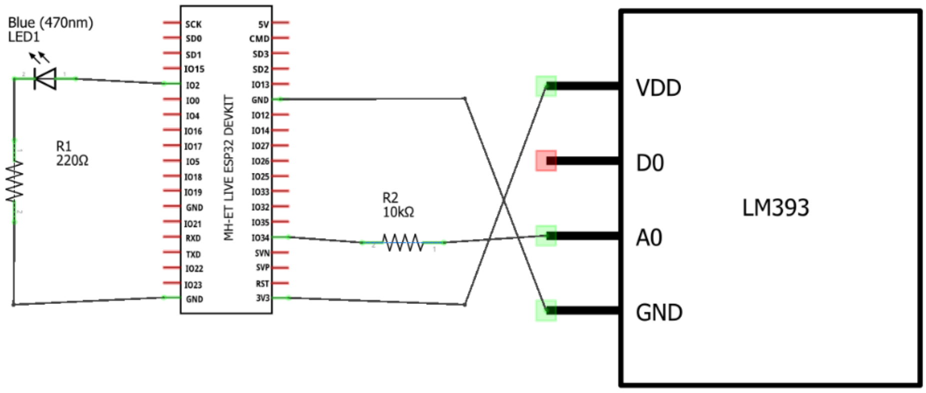


Fig. 3 *Schematic diagram of the system development*

Arduino IDE software is used in this research for writing, compiling and uploading code to the ESP32 microcontroller. The ESP32 provides processing power and memory, enabling the implementation of complex algorithms and data processing tasks required for oil spill detection. ESP32 also provides communication capabilities such as Wi-Fi and Bluetooth which are essential to integrate the system with IoT application. This allows for real-time monitoring of the oil spill detection system. The analog-to-digital converter (ADC) is also a vital function in the ESP32, since the analog signal from the photodiode can be converted into digital format such as voltage for further analysis. Fig. 4 shows the steps required in developing the oil spill detection.

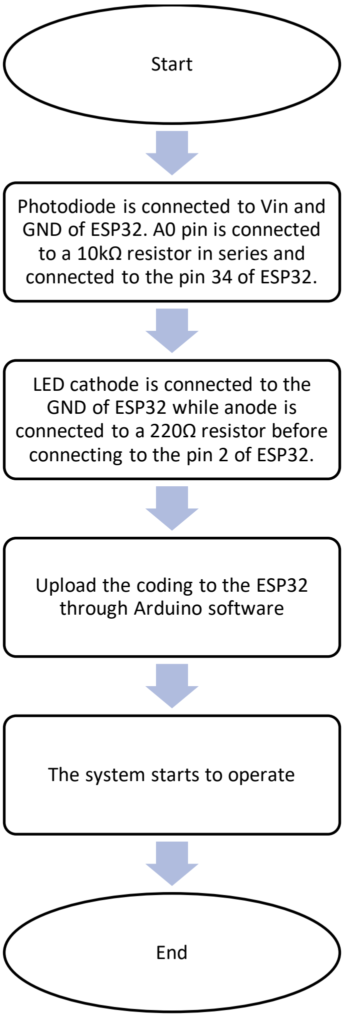


Fig. 4 *Flowchart of the system development*

2.4 Buoy Design

A floating buoy is designed for the LED-based sensor oil spill detection and thickness measurement using TinkerCAD [25]. Based on the design, the distance between the detector (photodiode) and the light source (LED) can be adjusted. The buoy construction is mostly made up of four rods that are parallel to one another and may each support many floaters. Two different platforms are used to link the rods together. The floaters were chosen for the design's stability and a waterproof light casing that is resistant to water wear are used for simple and reliable deployment. The yellow casing is used to place the ESP 32 module and the photodiode. Then, blue LED is placed at the bottom of the platform where it can beam its light upwards to the photodiode that is placed at the upper platform (Fig. 5).

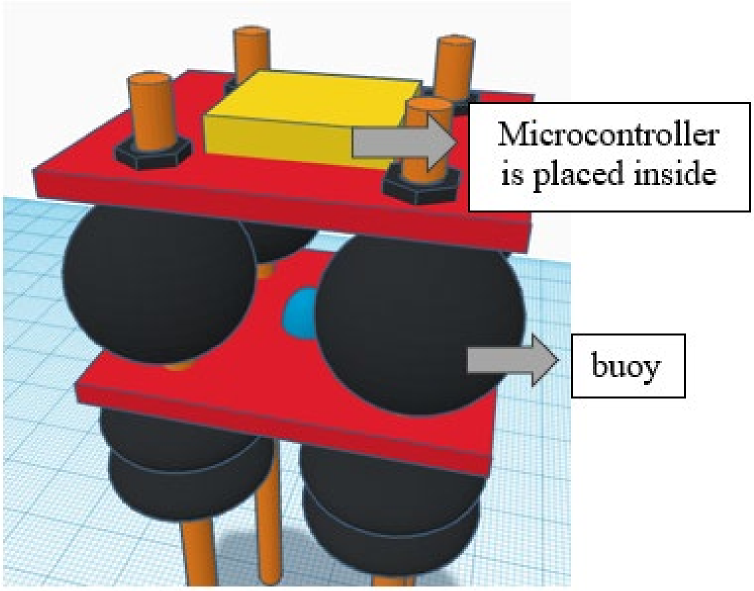


Fig. 5 *Buoy design*

2.5 Operation of Oil Spill Detection using Optical Sensor with IoT System

Fig. 6 illustrates the flowchart of the system. First, the system measures the light intensity that passes through the oil slick in water. After that, the light intensity (analog value) is converted to voltage by using ADC formula, to be easily processed by the microcontroller [26]. Then, the resistance value is calculated using voltage divider rule (VDR) equation. If the resistance value is below 18 kΩ [15], then, there is oil presence in the water. The value is sent to the IoT application, and an alert message appears to notify the user.

The measured analog signal value represents the amount of light that the optical sensor can detect. The number of discrete levels or steps that the ADC can represent refer to its resolution. To convert the measured light intensity to a voltage value, the ADC formula divides the measured signal value by the maximum possible value represented by the ADC resolution. The ESP32 has 12-bit ADCs. Thus, the ADC resolution of microcontroller is 212 or 4096 steps.

The maximum number of the ADC resolution is 4095 since it varies from 0 to 4095 to give a total 4096 steps. The equation to obtain the voltage is shown in eq. (1) where the system voltage for ESP32 is 3.3 V [26].

$$V = \frac{Intensity\ of\ light\ values}{Resolution\ of\ ADC} \times System\ voltage \tag{1}$$

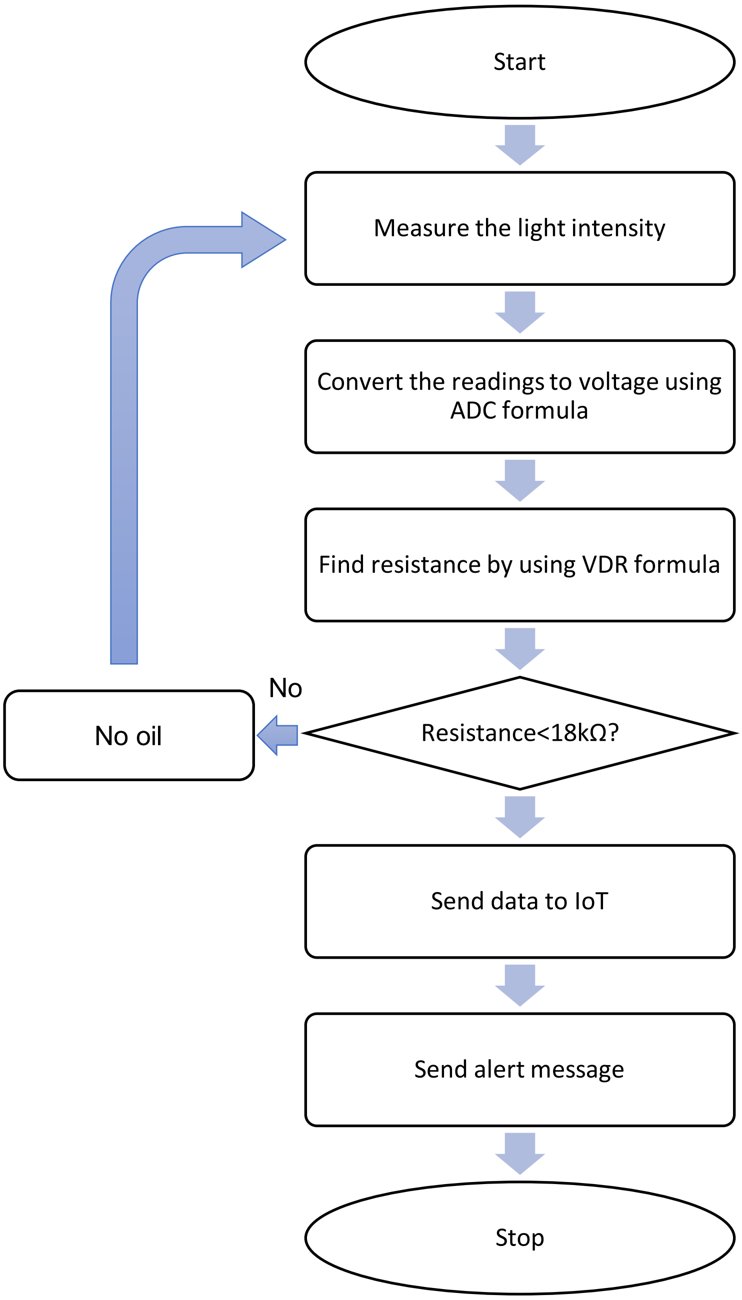


Fig. 6 *Flow chart of the operational system*

We can further analyse the data by determining the resistance value using the VDR formula after obtaining the voltage value through the ADC conversion. We can calculate the resistance using the VDR formula based on the measured voltage and the characteristics of the circuit. Usually, a series connection of a known resistance (R_2) and an unknown resistance (R1) is used to build the voltage divider circuit. The measured voltage is applied across an unidentified resistance (V_{out}). The VDR formula is shown in eq (2). V_{out} refers to the calculated voltage, R_2 is the resistor connected in series with photodiode (10kΩ) and Vs is the system voltage for ESP32 which is 3.3V.

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_s \tag{2}$$

The light intensity is converted to resistance using a light-dependent resistor (LDR), where higher light intensity decreases resistance and lower light increases it. This resistance change is measured in a voltage divider circuit with a fixed resistor. The output voltage is then read by an ADC (analog-to-digital converter) in a microcontroller, which calculates the resistance using eq (2).

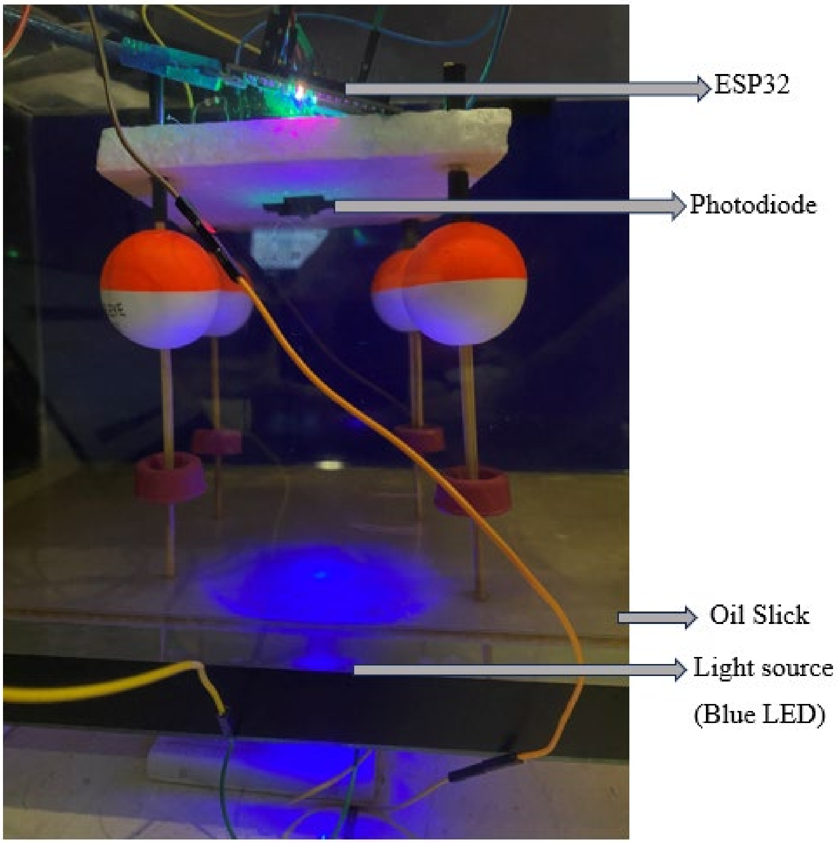
2.6 Experimental Setup

The experiments consist of varying the distance between the LED and photodiode, the volume of engine oil after figuring out the best distance and the exposure time. The configuration ensures reliable measurements of oil spill detection.

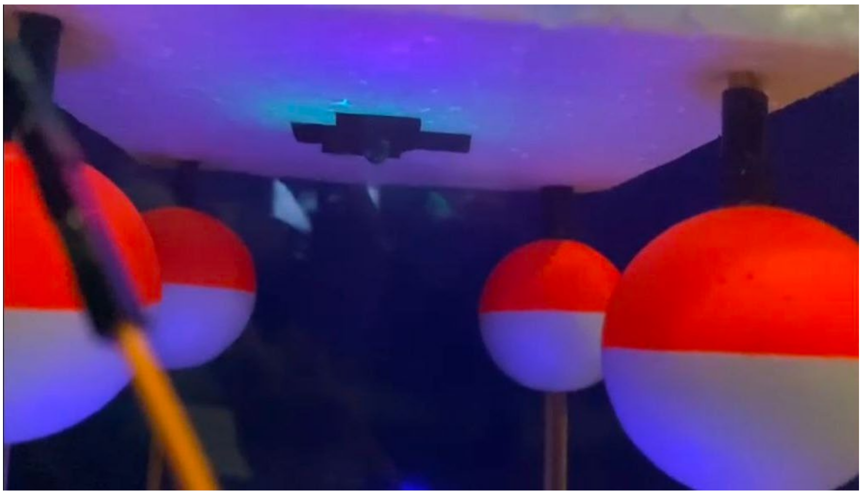
The experiment starts by testing a pure water sample without oil. This serves as a reference to establish the baseline resistance value for pure water. An aquarium is used to carefully collect and store water samples. Next, the light source and the photodiode are positioned at an initial distance (8cm). The system is then powered on by a power bank, and the photodiode measure the intensity of light for 6 hours. This measurement serves as the baseline for the resistance value of the water without oil.

To evaluate the effect of distance on the amount of detected light, the distance between the light source and the photodiode is varied systematically. The distance varies from 6 cm to 9 cm. At each distance, the light intensity is measured, and the corresponding resistance value is recorded. In this experiment, volume of oil is constant (100ml), and each measurement is taken in 6 hours. The data is analyzed to find the optimum distance once the resistance values for various distances have been obtained. We identify the optimum distance as the distance that can constantly give resistance values below 18kΩ and still can give output even after 6 hours after oil is added to a water sample.

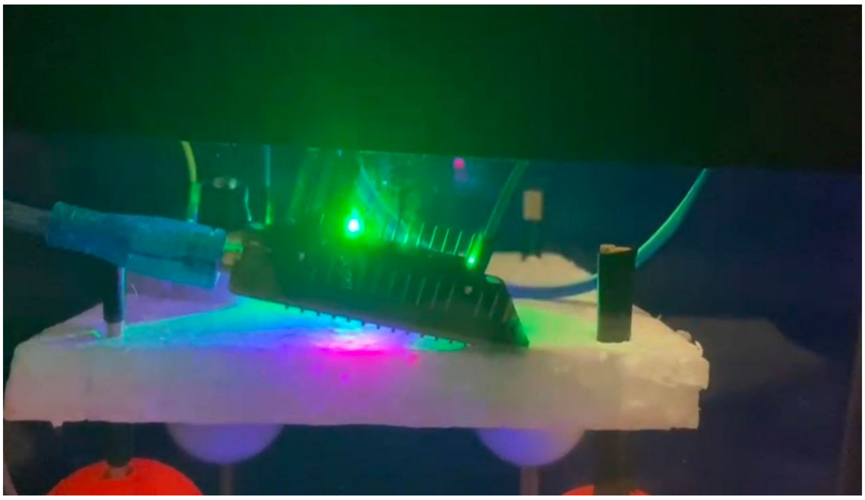
Once the optimum distance is determined, the experiments are continued by varying the volume of engine oil added into the water. Various volumes of oil (50ml, 100ml, 150ml and 200ml) are tested in 1 litre of water in an aquarium. The volume of the oil is scaled down from the real application based on the size of the aquarium. Fig. 7 shows the experimental set up for the proposed system and the experiment is repeated three times.



(a) Front view



(b) Side view



(c) Top view

Fig. 7 *Proposed system setup (a) Front view; (b) Side view; (c) Top view*

3. Results

This section depicts results from the experiment: resistance values of water without oil, resistance values for various distances between light source and photodiode, resistance values for various volumes of oil and real-time monitoring using Blynk platform.

3.1 Resistance Values of Water Without Oil

The resistance values of water without oil for six hours serve as a reference or baseline for the system. Accurate measurement and quantification of resistance changes caused by the presence of oil in the water sample is achieved by establishing the resistance of pure water. This allows us to distinguish between pure water with water contaminated with oil. In pure water without any substances, resistance value should be relatively high (Braun, 2017). Fig. 8 illustrates the resistance value of water without oil from the first hour until the sixth hour.

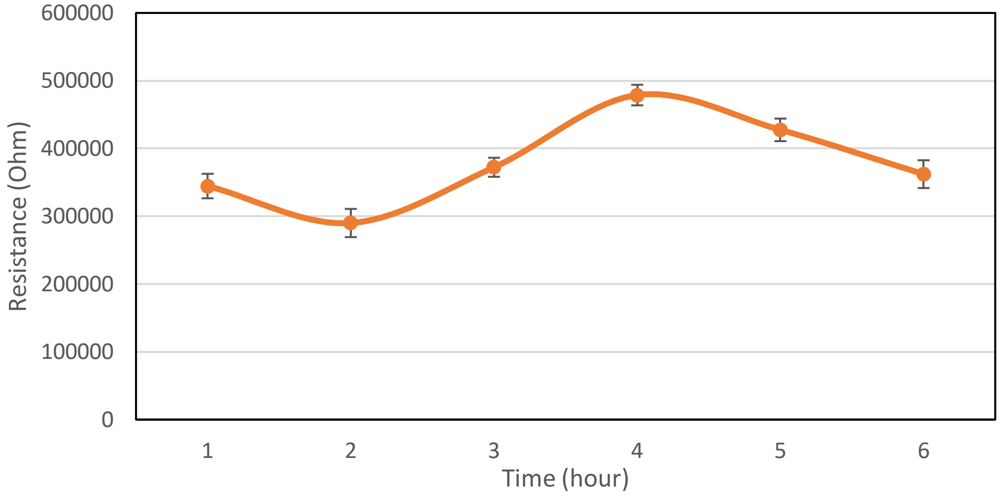


Fig. 8 *Resistance of water without oil*

The highest resistance value is at the fourth hour with value around 480kΩ while the lowest value is at the second hour with value around 290kΩ. The variation of resistance values is attributed to environmental or experimental conditions such as room temperature, closed room and humid conditions. Thus, we conclude that when there is no oil presence in water, the resistance value lies in between 280kΩ to 500kΩ.

3.2 Resistance Value for Various Distances

The distances of the photodiode and the LED vary from 6 cm to 9 cm whereas the volume of oil used is fixed to 100 ml. The experiment is conducted on the same day for 6 hours. In theory, the closer the distance between light source and the photodiode, the more sensitive it is [27]. This is because the photodiode is made of a semiconductor material that conducts electricity more easily when it is exposed to light. When the light sensors beam towards the photodiode, the oil absorbs some of the light before it hits the sensor [28]. This causes a decrease of light intensity resulting in lower resistance value than water without oil. By analyzing the results of resistance values with various distances, we observe that the changes in the distance parameter affect the system's performance. It enables us to determine the distance at which the resistance of the system changes when there is oil in the water sample. The resistance values of various distances from light source to photodiode with fixed oil volume is depicted in Fig. 9.

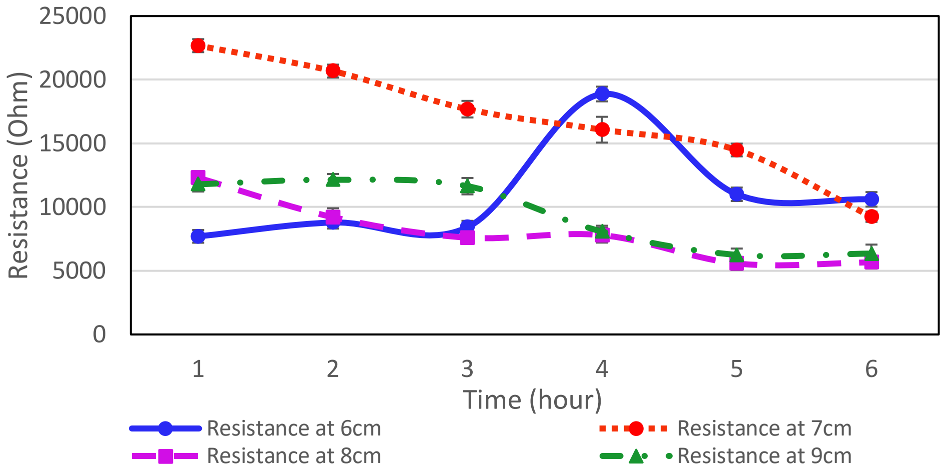


Fig. 9 *The resistance values for various distances from light source to photodiode throughout 6 hours*

3.3 Resistance Value for Various Volumes of Oil

In the experiment which involves various volumes of oil, the distance is fixed at 8 cm and conducted on the same day with each volume is tested for 6 hours. The purpose of this experiment is to ensure that the system responds to the various oil volumes and evaluates its sensitivity and accuracy to sense oil in water. The system's responsiveness and sensitivity to varying oil spill concentrations can be understood by analyzing the results for different oil volume scenarios. We may use the generated resistance values to assess the system's detection limits and to determine how well it can distinguish between minor and large oil spills. When the quantity of oil increases, the intensity of transmitted light decreases due to light absorption of the oil slick, resulting in lower resistance value. The resistance values of various volumes of oil are depicted in Fig. 10. Fig. 10 shows the resistance values for 50 ml, 100 ml, 150 ml and 200 ml of oil.

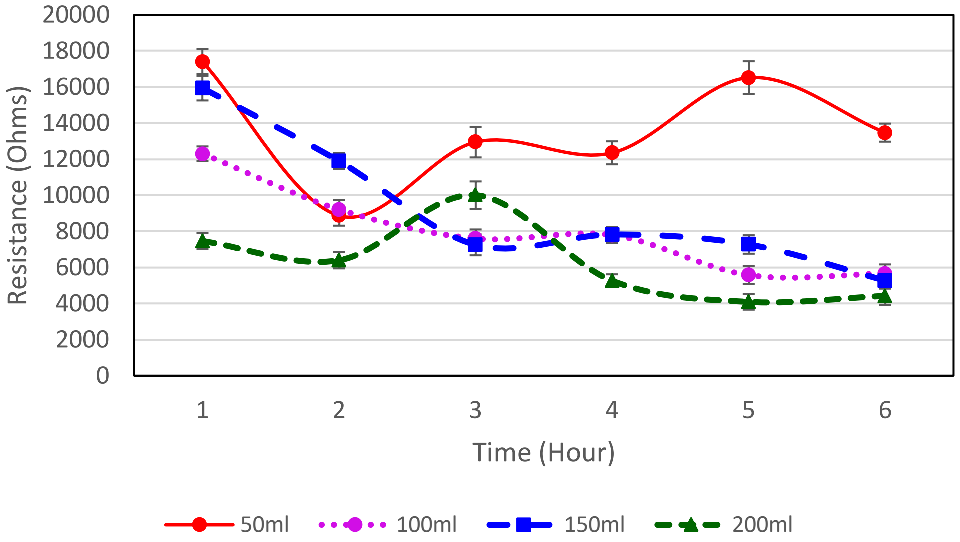


Fig. 10 *The resistance values for various volumes of oil*

3.4 Resistance Value for Various Exposure Time

The exposure time of oil in water is studied based on resistance values. The time is varied from 1 hour to 6 hours for different volumes of oil (Fig. 11). At the first hour, the resistance value depicts highest value, 17.4 kΩ for 50 ml of oil and the measurement fluctuates for the rest of the volumes of oil. The fluctuation continues for the second hour until the fifth hour. After the sixth hour, the resistance value decreases when more oil is used. At this hour, the sample becomes cloudy and turbid.

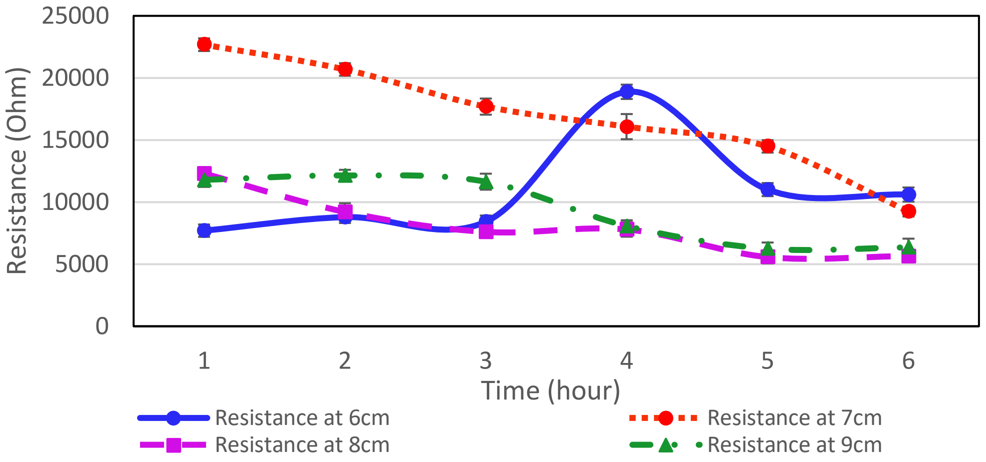


Fig. 11 *The resistance values of sample for various exposure time*

3.5 Real-Time Monitoring using Blynk

The real-time monitoring is done using Blynk, an IOT platform. The monitoring process of detecting oil in water can be observed through Blynk on mobile phone and web dashboard. Fig. 12 shows the display through the mobile Blynk application which shows the resistance value. The graph in Fig. 12 is generated after the resistance values are updated to the Blynk platform.

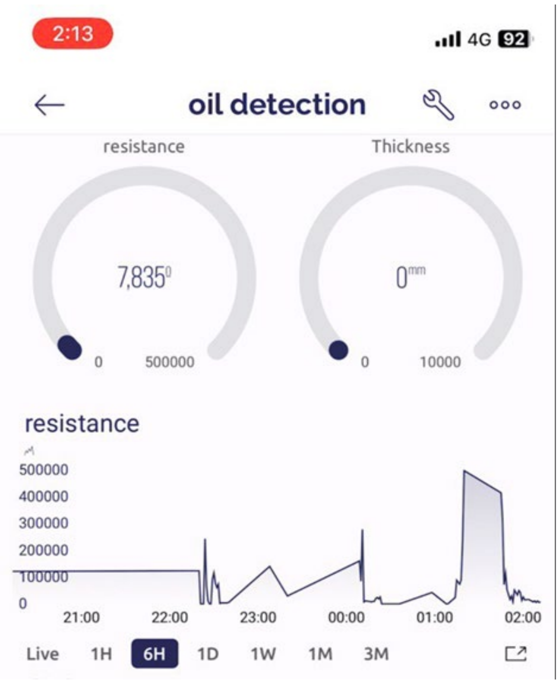
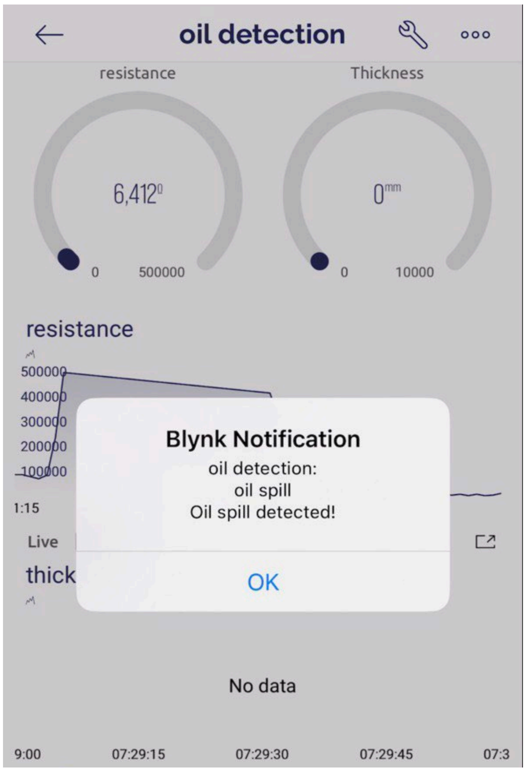


Fig. 12 *Message appeared in the Blynk application to notify user*

Fig. 13 and Fig. 14 show the alert message appeared if the resistance value is below 18kΩ, indicating that there is oil spill in the water.



Blynk Notification
oil detection:
oil spill
Oil spill detected!

No data

Fig. 13 *Message appeared in the Blynk application to notify user*

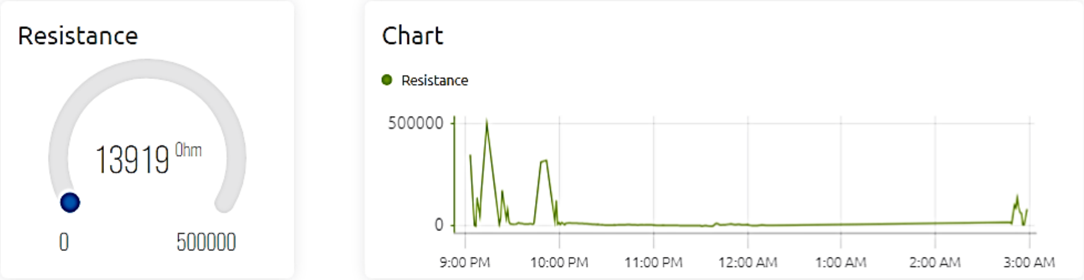


Fig. 14 *Real-time monitoring through web dashboard*

A low-cost oil spill detection using optical sensor with IoT is built to measure the resistance from photodiode in order to evaluate the intensity of transmitted light. The measurement is analyzed to detect the presence of oil in water.

The resistance value for the oil-free water sample (Fig. 8) shows less fluctuated data. This demonstrates that the absence of oil in the water allows for consistent light transmission, which produces a constant reading of resistance. The result becomes a reference for the next measurement which involves oil in water.

Fig. 9 shows that resistance value is relatively low even though only at the first hour (distance of 6 cm). It suggests that the oil spill detection system quickly detects the presence of oil in the water sample. At the fourth hour, the resistance value increases above 18kΩ. This variation could be due to experimental conditions where there is a small amount of oil surrounding the light source. Then, Fig. 9 also shows a linear decreasing graph where the peak resistance value lies at the first hour with 22.7kΩ (distance of 7 cm). This is because there is less interaction of water and oil. After 6 hours, the system records the minimum resistance value with 9.2kΩ since after some time, the oil can interact with water leading to cloudy and turbid water. Then, the resistance is 12.3kΩ, the highest value for distance of 8 cm at the first hour. This indicates that the oil slick does not absorb much light from the blue LED. As the exposure time is increased to 5 hours, the resistance value drops to the lowest, 5.5kΩ and the value maintains at the sixth hour, 5.6kΩ. A decrease trend is observed for 9 cm. At first three hours, the resistance value maintains but for the next three hours, the resistance value decreases since water becomes cloudy and turbid, causing difficulties for the photodiode to sense the light intensity [29]. It shows that, longer time of oil in the water causes less light detected by the photodiode. In a real situation, oil can block and prevent sunlight from reaching aquatic life in the water that eventually destroys plant photosynthesis and growth. The distance of 8 cm shows quite stable and less fluctuated resistance value throughout the experimental duration. Less fluctuated value is crucial to make sure that the system can consistently detect and monitor oil spills over a long period of time without experiencing major changes in the resistance values. These criteria led to the conclusion that the ideal distance for the system is 8 cm.

Then, the effect of oil volumes is studied as well. For 50 ml oil, the resistance value fluctuates for 6 hours shown in Fig. 10. The average resistance throughout the 6-hour period is quite high but it is still below the threshold value. It can be due to a slightly clearer medium for light to pass through directly to the photodiode. For 100 ml oil and 150 ml oil, the resistance decreases over 6 hours period. We attribute that to the oil molecules that start to spread in water. This is because the oil molecules diffuse into the water, which increases the conductivity of the mixture. The rate of diffusion is fast, causing the resistance to decrease rapidly in the first few hours [30]. For 200 ml, the resistance reduces except for the third hour that shows the peak of resistance value. These findings show that larger volumes of oil spills can produce thicker oil layers causing more light obstruction into the water. We attribute the condition to the fact that oil particles in the water can obstruct light transmission [31].

In terms of exposure time, the fluctuation of the resistance values occurs for five hours, and the resistance values reduces gradually for the sixth hour (Fig. 11). This condition occurs might be due to the dissolution and dispersion of oil in water [32].

The oil can be monitored using a computer and a mobile phone through an IoT platform (Fig. 12-14). The consumers can monitor the resistance value in Blynk application and obtain notification on oil spill from the system.

Thus, oil spills can endanger aquatic life since there will be less air that consists of oxygen and carbon dioxide and other gases that goes into the water. Air particles are much lighter than oil particles. When air particles collide with oil particles, the air particles tend to move back to the atmosphere due to the difference in particle densities. Therefore, oil spills can harm birds, mammals and aquatic life in terms of toxic contamination, physical contact and destruction of food sources and habitats [33].

Overall, the findings show that the developed system is reliable to detect oil spills. The discussion focuses on the effects of varying oil volumes, distances and exposure time on the resistance values, offering insights into the system's behavior. Oil in water not only causes bad physical contact and is toxic to animals but also can prevent light and air from reaching life under the water.

4. Conclusions

In conclusion, the study demonstrates the detection of oil spill in water using a photodiode by designing and implementing a system that is based on light propagation and IoT. Several parameters such as oil volumes, distance of oil spills and exposure time are examined to investigate their impact on the operation of the system. The findings show that the resistance values are significantly affected by the distance of photodiode and LED, with increasing distance results in a decrease in resistance. Similarly, the amount of oil affects the resistance readings, initially producing higher resistance that eventually drops over time. With its great sensitivity and quick response time, the photodiode can detect changes in light intensity. The system detects the presence of oil in the water by converting the measured light intensity to voltage using the ADC method and then calculates the resistance value using the VDR formula. Potential damage to the environment and financial losses can be reduced by enabling real-time monitoring through integration with IoT. Furthermore, the advantage of low-cost systems allows for widespread adoption and deployment in various regions, especially in areas where oil spills in irrigation ditches pose a significant risk. The community benefits from increased awareness and proactive measures to safeguard agricultural resources and livelihoods.

In future, study will involve different types of oil that have the possibility to pollute irrigation canals, rivers or oceans. The system should be subjected to outdoor testing in real-world conditions, including different water bodies. This can help to validate the system’s performance and accuracy in detecting oil spills. Additionally, the minimum range of oil quantity that can be detected by the proposed system will be determined in the experiment. Other than that, the future study will consist of oil detection in river using light detection and ranging (LIDAR).

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Conceptualization****: N.N.C.S. and W.Z.W.I.****; methodology,*** *N.N.C.S. and W.Z.W.I.****; software:*** *N.N.C.S.****; validation:*** *W.Z.W.I. and M.F.H.M.A.H****; formal analysis:*** *N.N.C.S.****; investigation:*** *N.N.C.S.****; resources:*** *W.Z.W.I****; data curation:*** *N.N.C.S.****; writing—original draft preparation:*** *N.N.C.S. and W.Z.W.I.****; writing—review and editing:*** *N.A.A.A, W.M.W.A.K and A.K.G.****; visualization:*** *N.N.C.S.****; supervision:*** *W.Z.W.I.****; project administration:*** *W.Z.W.I.****; funding acquisition:*** *N.A.A.A and A.K.G. All authors reviewed the results and approved the final version of the manuscript.*

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