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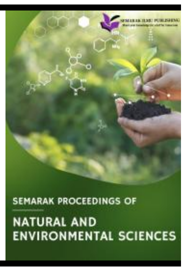

Oil Pollution Sensing Based on Light Detection and Ranging

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ABSTRACT

We have developed a system for oil pollution detection using Light Detection and Ranging (LiDAR) technology. The system utilizes a TFmini-S LiDAR sensor and an ESP32 microcontroller to detect the presence of oil in freshwater. The LiDAR sensor emits laser pulses and records the reflection patterns from the water surface. The sensor identifies changes in reflected light intensity due to the presence of oil, distinguishing between clear water and oil-contaminated water. Experiments were conducted in controlled laboratory conditions using two types of oil samples: new gasoline oil and used gasoline oil. These samples were mixed with water to simulate oil pollution scenarios. The sensor readings were continuously monitored, and the data was analysed to assess the effectiveness of the system. Results show that the system could detect changes in surface properties caused by oil, with distinct patterns observed for new and used oil samples. New oil demonstrated more stable sensor readings due to its uniform surface properties, while used oil exhibited fluctuations, likely due to impurities and varied surface textures. This research confirms the feasibility of using LiDAR technology to detect oil in freshwater environments. The system offers a non-invasive and real-time method for monitoring water quality and detecting oil pollution. Future work will involve optimizing the system for field deployment, including testing under varying environmental conditions such as temperature, light, and water movement. This study contributes to the development of LiDAR-based environmental sensing systems for pollution monitoring, providing a potential tool for environmental agencies and water management organizations to detect and manage oil spills effectively.

Keywords: *Oil; oil pollution; light intensity; light detection and ranging; sensor*

1. Introduction

Oil pollution sensing is critical for monitoring environmental contamination in water bodies. Accurate detection helps preventing long-term ecological damage. Remote sensing refers to the collection of information about an object without direct physical contact [1]. The most popular method for mapping and detecting oil spills using remote sensing is to map the sea surface using passive observation. One of the remote sensing methods involves the usage of cameras in the visible and infrared spectrum [2]. The method is cost-effective, especially when it comes to operations support countermeasures.

Ultraviolet and near infrared are less applied probably because of the light source and detector's constraint [3]. Satellite and airborne sensors are employed to obtain data on water quality, temperature, and other environmental variables. For seawater, remote sensing helps in monitoring sea surface temperature, chlorophyll concentration, and ocean color, which indicates phytoplankton

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abundance and overall water quality [4]. For lakes and rivers, remote sensing can provide information on water turbidity, sediment transport, and shoreline changes [5].

Remote sensing technologies, such as LiDAR, offers unique advantages in detecting and monitoring oil spills in aquatic environments. LiDAR, refers to Light Detection and Ranging, utilizes laser light to measure distances and generate precise three-dimensional representations of the Earth's surface [6]. The basic principle of LiDAR involves the emission of laser pulses towards a target area, and the measurement of the time it takes for the laser light to travel to the target and back [7]. This time-of-flight information is then used to calculate the distance between the LiDAR instrument and the target, enabling the generation of precise topographic and spatial data [8]. The principle of LiDAR relies on the speed of light and precise timing measurements to accurately determine distances. LiDAR systems can operate in various modes, including topographic LiDAR for terrain mapping, bathymetric LiDAR for underwater mapping, and atmospheric LiDAR for studying the composition and characteristics of the atmosphere [9].

Thus, the goal of this research is to develop oil pollution sensing using LiDAR method in detecting the presence of oil in freshwater. The research system uses a TFmini-S LiDAR sensor and an ESP32 microcontroller to detect oil pollution in freshwater. The TFmini-S LiDAR operates by emitting laser pulses and measuring the reflection from the surface of the water. The microcontroller processes the data and identifies changes in the reflected light caused by oil on the water surface. The experiment involves testing the system in controlled environments, with both oil-contaminated and clean water. The sensor readings were collected and analyzed to differentiate between the two conditions. This study provides insights into using LiDAR for monitoring oil pollution in freshwater environments.

2. Methodology

2.1 Selecting Oil Sample

Two types of engine oil are used in this research. The first is Blaze Racing Multi-Grade SAE 20W-50 API SL, a gasoline engine oil designed for high-performance engines. It is new and exhibits a clean, clear appearance. The second sample is used engine oil, collected from a workshop after being utilized in a vehicle. This oil is darker and has a cloudy, contaminated appearance due to its previous use. The primary distinction between these oils lies in their appearance and color. The volume of oil used is 200 ml mixed with 1 liter of plain water.

2.2 Operation of Oil Pollution Sensing Using LiDAR

The LiDAR can identify obstacles by directing a laser beam and employing a sensor to capture the reflected beam [10] (Figure 1). The laser transmitter emits pulsed laser light in a specific direction. When the beam hits an object, it reflects or diffuses, depending on the surface material. The laser detector receives the reflected signal. It measures the time taken for the laser to travel to the object and back. Using this time, the distance between the sensor and the object is calculated. This method determines distance through the time-of-flight principle. Time-of-flight (ToF) is used to compute the distance between the identified barrier and the receiver. The process is essential for precise distance measurements in various applications. Eq. (1) states that the distance can be computed by calculating how long it takes for the pulse to be emitted to reach the target, reflect some of the ray, and then return to the LiDAR's receiving lens.

$$r = \frac{c}{2n} \cdot \Delta T \tag{1}$$

where c is the speed of light, which is a universal physical constant; n is the refractive index of the propagation medium, which is 1 for air; ΔT is the time difference between transmitting and receiving laser pulses [11].

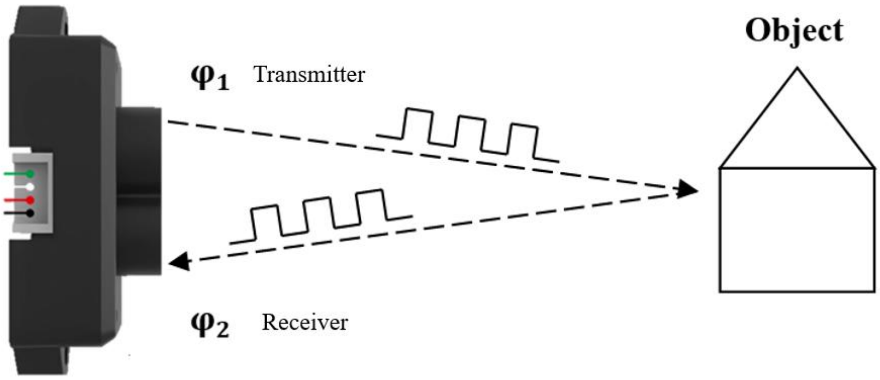

Fig. 1. Diagram of the time-of-flight (ToF) principle [12]

2.3 Circuit Connection

Figure 2 shows the circuit connection of ESP32 with TFmini-s LiDAR sensor according to Table 1. The sensor was connected to pins of GPIO (TX & RX of ESP32).

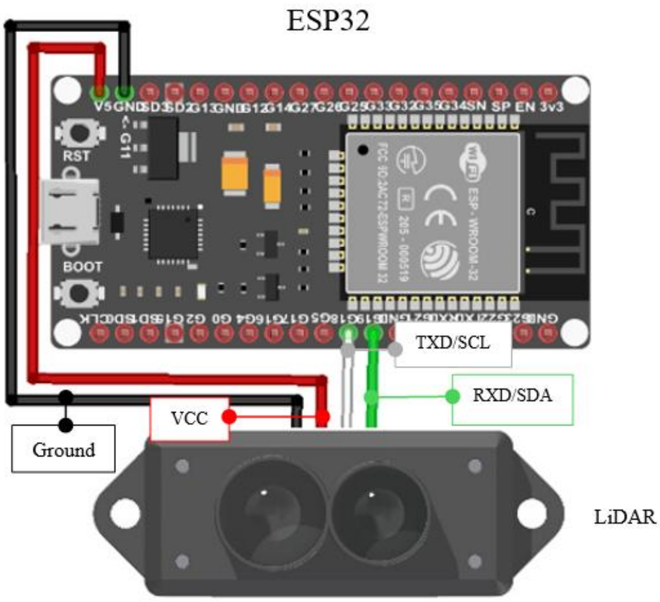

Fig. 2. The circuit diagram of the system

Table 1
Circuit connection

Component	ESP32	TFmini-s
Power source	Vin	VCC
Ground	GND	GND
Receiver	18	RX
Transmitter	19	TX

Figure 3 shows the system prototype. The glass tank was filled by water and oil. The output readings were collected in real-time using Data Streamer in Microsoft Excel.

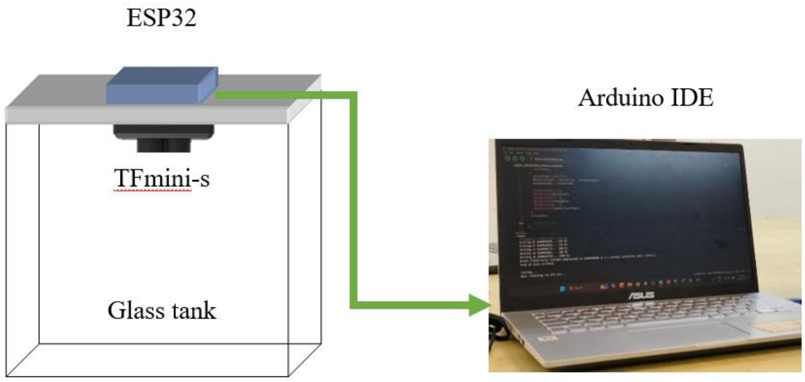

Fig. 3. The sketch of full prototype

Figure 4 shows the flow of overall process. It begins with the system initialization. The ESP32 microcontroller powers up and initializes the TFmini-S LiDAR sensor. The sensor collects distance and light intensity data from the water surface. The ESP32 processes the data and calculates reflection characteristics. Any significant changes in distance or intensity indicate the presence of oil. If no anomalies are detected, the system continues collecting data. From the results, when significant changes in reading are detected, that means the oil is present. The system then returns to continuous collecting data or ends the session.

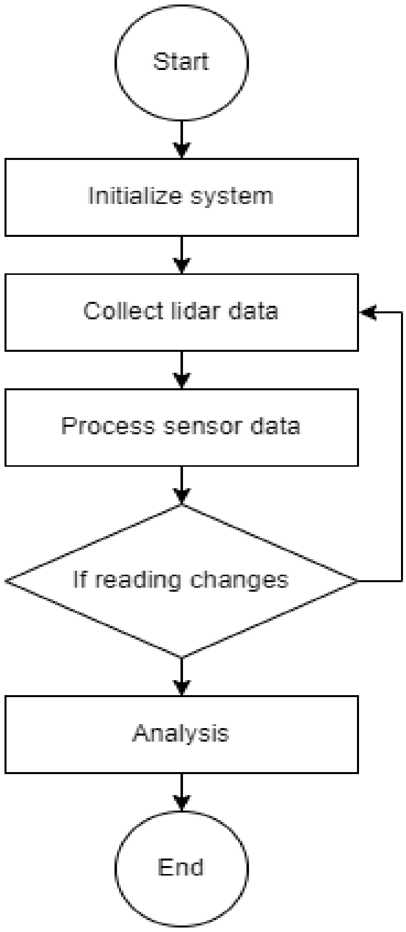

Fig. 4. Flowchart of overall process

3. Results

Table 2 shows the comparison data of distance from sensor to water surface and light intensity between new and used engine oil in this experiment.

Table 2
Results of comparison for both oil

Time (min)	Distance		Light intensity	
	New oil	Used oil	New oil	Used oil
0	16	13	11727	648
5	16	11	7523	459
10	16	9	2694	387
15	16	11	9629	443
20	16	11	10250	462
25	18	12	8800	447
30	17	11	8670	454
35	18	10	8056	442
40	17	12	7981	440
45	17	10	7996	432
50	17	9	7648	422

Based on the data provided for both new engine oil and used engine oil, the LiDAR sensor readings are affected by the presence of oil, as reflected in the variations in the measured distance and light intensity over time.

The distance for both oils fluctuate slightly over time. New oil maintains a relatively stable distance between 16 and 18 cm. Used oil shows a gradual reduction in distance, reaching 9 cm after 50 minutes. The light intensity for new oil decreases significantly from 11727 to 7648. For used oil, the intensity remains mostly stable, varying from 648 to 422. Both oils exhibit noticeable changes over time, with larger shifts in light intensity.

New oil shows higher light intensity compared to used oil across all time points. The distance for new oil remains shows less fluctuation than used oil. The new oil has a more uniform surface than the used oil. This uniformity causes fewer fluctuations in LiDAR readings. Used oil often contains impurities and uneven textures. These can scatter the LiDAR beam, causing unstable readings. For example, particles in used oil can create multiple reflections. This affects the sensor’s ability to detect accurate distances. New oil also has better clarity, which improves beam transmission. In contrast, cloudiness in used oil distorts the LiDAR signal. These factors result in more consistent distance readings for new oil compared to used oil. Used oil absorbs or scatters more light, resulting in lower intensity. The optical properties of new oil allow better light transmission. Used oil reflects degradation, as seen in its reduced light intensity and distance values. These differences highlight varying oil conditions.

3.1 Comparison of Distance

Figure 5 shows the graph comparison of distance between using new and used engine oil. The distance for new oil remains relatively stable, showing minimal fluctuation over time. For used oil, the distance follows a downward trend, gradually decreasing as time progresses. This indicates that the used oil affects the LiDAR sensor's ability to consistently detect the surface.

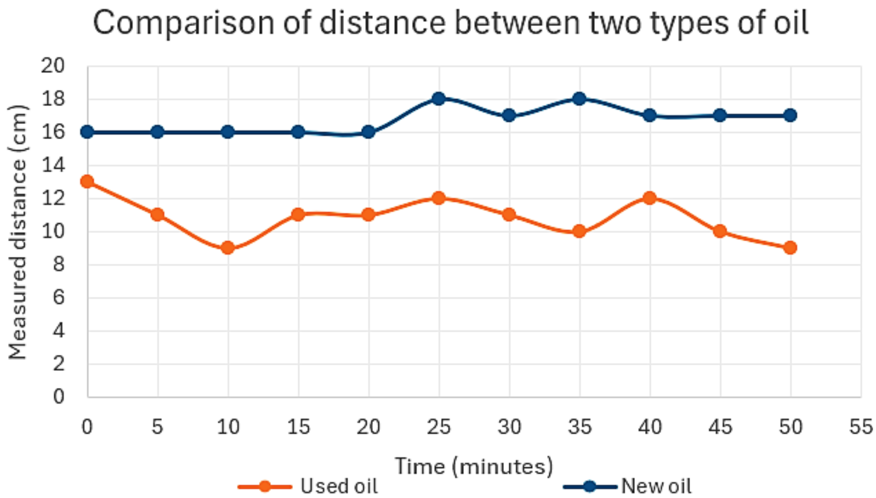

Fig. 5. Comparison of distance between using new and used oil

3.2 Comparison of Light Intensity

Figure 6 shows the graph comparison of light intensity between using new and used engine oil. For light intensity, new oil shows a clear declining trend. The intensity drops sharply in the first 10 minutes, then stabilizes. Used oil, however, displays a nearly constant trend with minor fluctuations. The lower and stable intensity for used oil suggests that its optical properties are less affected by the sensor over time.

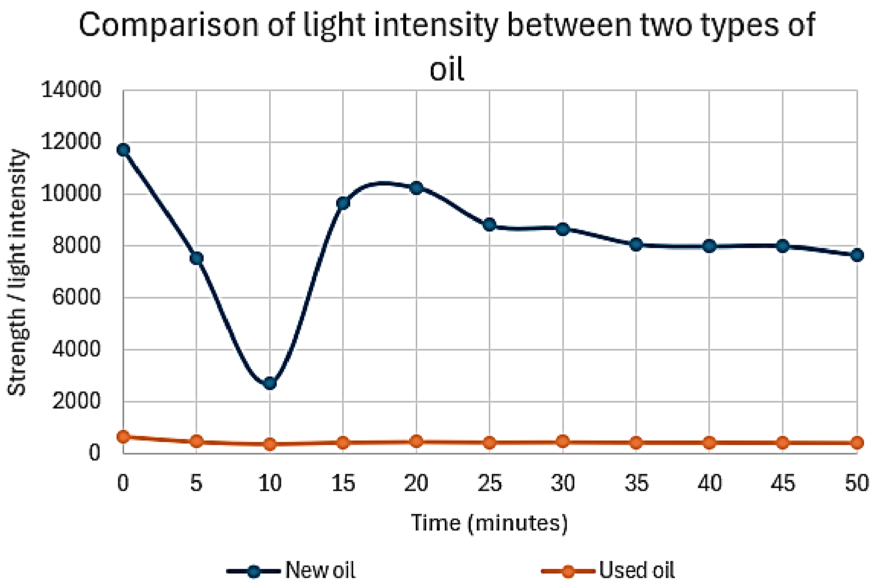

Fig. 6. Comparison of light intensity between using new and used oil

3.3 Analysis and Discussion

The system is observed to detect a difference in the LiDAR reflection patterns when oil is present on the water's surface. Since oil changes the reflective properties of the water surface, the sensor should report different distance values and light intensities compared to clean water. The presence of oil should cause an increase in light scatter or absorption, leading to distinctive data that the system can interpret as oil contamination.

Based on the results, the capability of the TFmini-S LiDAR is verified for detecting oil in water. The difference in reflection could be influenced by the thickness of the oil layer, ambient lighting conditions, and sensor alignment. Improvements in sensitivity or accuracy may be achieved by fine-tuning the sensor or adding additional sensors for cross-referencing. Potential challenges may include distinguishing between oil and other surface contaminants, which may require further calibration or algorithm development.

4. Conclusions

This research successfully demonstrated the use of LiDAR for detecting oil pollution. The developed system effectively identified oil presence in freshwater. The TFmini-S LiDAR sensor provided reliable data on water contamination levels. Future studies could have enhanced the system's accuracy and adaptability in various environments. This technology offered significant potential for environmental monitoring and pollution management. It could have contributed to more effective responses to oil spills and contamination events. Overall, LiDAR presented a promising tool for improving water quality assessment and preservation.

Acknowledgement
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