

# Detection of Hydrocarbon Oil in Seawater by Light Absorption Analysis

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**Abstract**—A new optical sensing method is proposed to detect hydrocarbon oil in the sea. As a sensing methodology, a light absorption analysis is used with a laser source and two different types of photodiode sensors. To obtain information about the presence of oil on water and the thickness of oil, the intensity of the penetrating light through the oil–water mixtures is measured. In the experiment, bunker C and lubricating oil are used, and three different lasers having different wavelengths are applied and compared for the selection of an optimal light source. By using a photodiode sensor, we can convert the intensity of the penetrating light through a liquid into an electrical signal. As a result, it is observed that the intensity of the light on the optical sensor decreases with an increase in the oil thickness. Through this relation, both the presence of oil and the thickness of oil can be determined. This result shows the applicability of a hydrocarbon detection sensor.

**Keywords**—Optical sensor, Hydrocarbon spill detection, Light absorption analysis, Blue laser, Photodiode

## I. INTRODUCTION

A hydrocarbon spill accident in the sea is a major catastrophe that can have bad effects on every life in the ocean. Hence, rapid detection of hydrocarbon and response are very important and helpful for the prevention of environmental pollution.

In response to this need, various types of hydrocarbon spill detection sensors for the ocean application have been developed, and some of them have been applied in a real site [1], [2]. However, these developed sensors have some economic weaknesses. The sensing methodologies of the initially applied sensors are based on laboratory analysis equipment, such as mass spectrometry. These sensors can analyse the detailed components of hydrocarbon as well as the type of hydrocarbon. However, these sensors are mostly large in size and require a long analysis time because of their many processes [3]. Then, an initial type of sensor, sensors that use fluorescence analysis by UV rays [4], and electrical capacitance measurement [5] were developed. These sensors can detect not only the existence of hydrocarbon but also analyse their components down to the parts per million level. However, these sensors are generally not cost effective, and it is therefore very difficult to increase the number of detection points in the ocean. To solve these problems of the existing hydrocarbon spill detection sensors, in this research, we have focused on the development of a sensor, which has advantages of cost-effectiveness with respect to installation and maintenance, and a simple detection mechanism. To realise these requirements, the difference in light absorption between oil and water is used as a sensing principle. Further, by using electro-optical devices such as laser and optical sensor, we have estimated the detection capability of a proposed sensor in this research. To select the optimal wavelength of the laser,

three different types of laser are compared and the prototype of the sensor platform is described in the body of paper.

## II. SENSOR DESIGN

### A. Sensing Principle

In this research, laser is used as a light source, and an optical sensor is used for evaluating the light intensity. These two electric devices are very cheap and easy to use, thus satisfying the aims of sensor development.

This research is partially motivated by existing research on the sensing mechanism [6], where light emitting diodes (LEDs) and light-dependent resistors (LDRs) were used for monitoring oil, with multiple LED/LDR pairs positioned vertically. In this former research, the detection resolution of the oil thickness was on the centimetre scale. However, in the current research, the light source (laser) is positioned underwater and the penetrating light energy is evaluated by the optical sensor above the water surface. Further, the optical sensor is used for directly converting the light intensity into voltage; hence, there is no need for an additional converting process. The changes made to the light source and the optical sensor are different from former research.

The methodology in this research involves the use of (1) a blue laser to illuminate the monochromatic high-powered light to the heavy oil in seawater and (2) an optical sensor to evaluate the intensity of the light that penetrated the oil in seawater. As the sensing principle, the difference in the light absorption rate between oil and water is used.

$$I = I_0 e^{-az} \quad (1)$$

where  $z$  = path length

$I_0$  = initial intensity of light

$a$  = light absorption coefficient

Equation (1) is Beer's law, which describes the light absorption in the seawater [7]. In this equation, the light absorption coefficient is dependent on the type of medium and the wavelength of light. If the light diffuses into different types of media, the decreasing tendency of the light intensity varies. Moreover, the wavelength of light is a major part of the determination of the condition of light absorption. If the light source having a different absorption characteristic between oil and seawater is chosen, using this light source, we can find out the oil existence and the oil thickness.

Normally, it is common sense that a light having a blue wavelength region has considerably selectivity with respect to an absorption rate when it penetrates the oil in seawater. When a blue light diffuses through oil or seawater media, the light is considerably more absorbed in the oil than in seawater. Hence, with an increase in the oil thickness, the possibility of light attenuation in the oil layer increases (see Fig. 1). Therefore, the energy of the penetrating light on the optical sensor will decrease. By using this optical sensing mechanism, we can

monitor the existence and the thickness of oil on the water. Hence, in this research, three different types of lasers (blue, green and red) are compared for the selection of an optimal light source, which has considerable selectivity between oil and seawater.

**B. Experiment**

To determine the optimal wavelength of the laser, experiments are conducted using three different lasers (473 nm for blue, 532 nm for green and 650 nm for red) with increasing oil thickness (see Fig. 2). For the exact measurement of light intensity, external lights (sunlight and electric light) are blocked by a black box. Further, the oils used in the experiment are lubricating oil and bunker C oil (type A), which can be very harmful when spilt in the ocean.

Two different types of optical sensors are used in the experiment. The first one is a 2 × 2 photodiode array shown in Fig. 3. This sensor can transduce the light intensity to the voltage output. The supply voltage of this sensor is 5.0 V, and the output range is 0.8 V–5.0 V. The gap between the laser and the water surface is 5 cm. The measurements are conducted five times under the same condition at each case of laser. In the measurement of bunker C oil, a 2 × 2 photodiode array sensor is applied to measure the light intensity. The increment in the oil thickness is 0.5 mm, and the experiment is conducted up to a thickness of 2 mm.

In the second experiment, the lubricating oil is used, and the optical sensor having a single photovoltaic photodiode is applied to evaluate the light intensity (see Fig. 4). This optical sensor operated under an unbiased condition and output the

current signal. The increment in the oil thickness is 1 mm, and the experiment is conducted up to a thickness of 4 mm.

**C. Results**

In the first experiment (bunker C oil), the sensor output results obtained using blue, green, and red lasers under conditions of increasing oil thickness are shown in Figs. 5–7. Through these three results, in the case of the blue laser, it is observed that with an increase in the oil thickness, the intensity of the light decreases linearly and the selectivity is the highest among the three laser sources. Hence, the blue laser is the optimal light source for the detection of oil presence and the measurement of the thickness of the bunker C oil.

In the second experiment (lubricating oil), the sensor output results obtained using blue, green, and red lasers under the conditions of increasing oil thickness are shown in Figs. 8–10. Through these three results, in the case of the blue laser, it is also observed that when the oil thickness increases, the intensity of the light decreases linearly and the selectivity is the highest among the three laser sources. Green and red lights generally have a low power output. This implies that these lights are absorbed mostly in the seawater layer. Hence, the blue laser is also the optimal light source for the detection of oil presence and the measurement of the thickness of the lubricating oil.

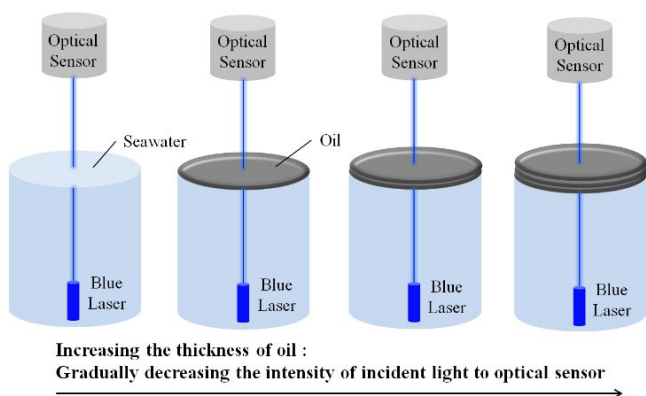


Figure 1. Schematic representation of the sensing mechanism

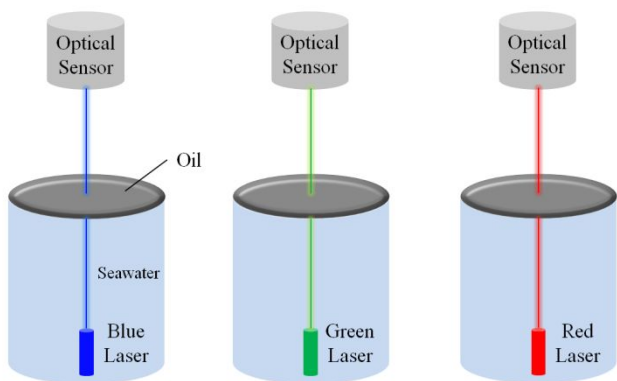


Figure 2. Experimental setup to select a laser as an optimal wavelength light source for the oil-spill detection sensors

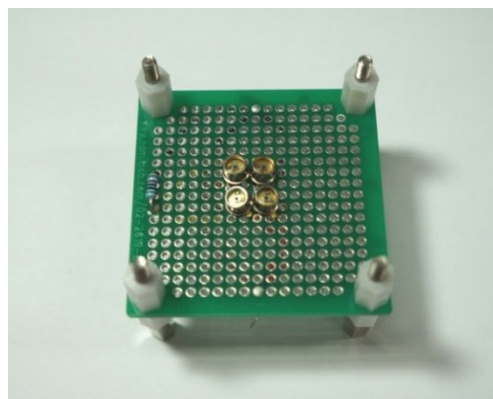


Figure 3. First optical sensor used in the bunker C measurement (2 × 2 photodiode array and voltage output)

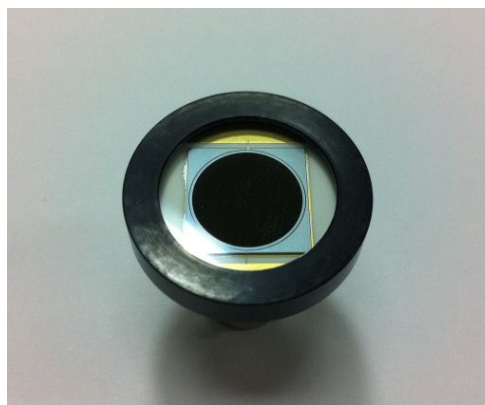


Figure 4. Second optical sensor in the lubricating oil measurement (Single photovoltaic diode and current output)

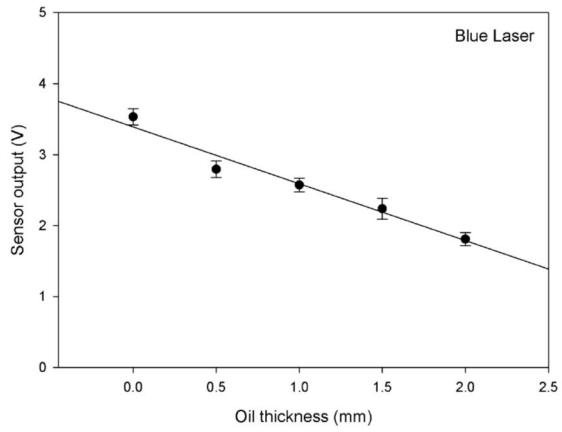


Figure 5. Sensor output results using a blue laser in bunker C oil

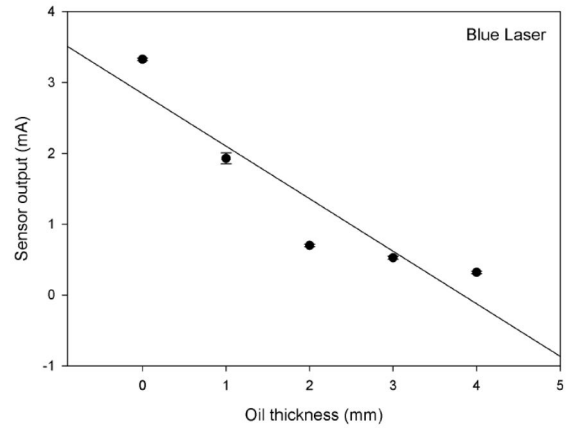


Figure 8. Sensor output results using a blue laser in lubricating oil

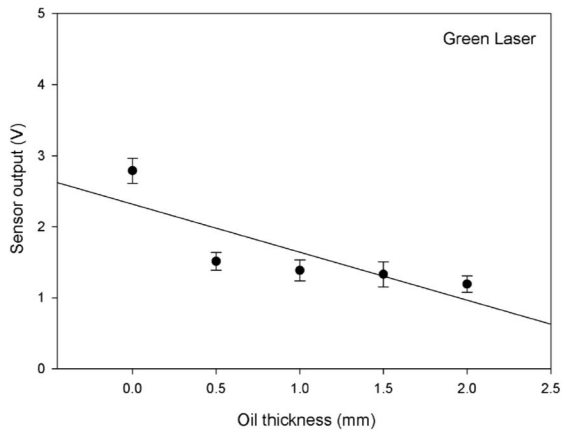


Figure 6. Sensor output results using a green laser in bunker C oil

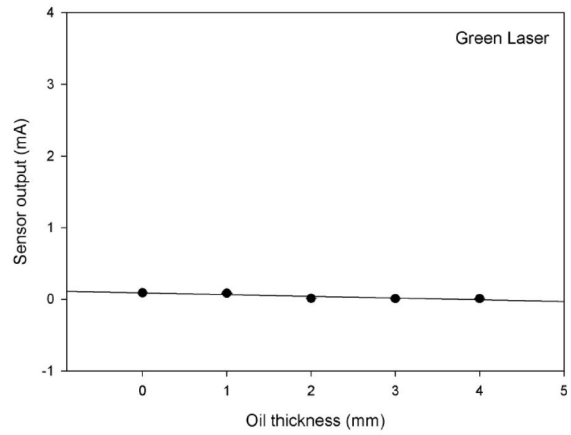


Figure 9. Sensor output results using a green laser in lubricating oil

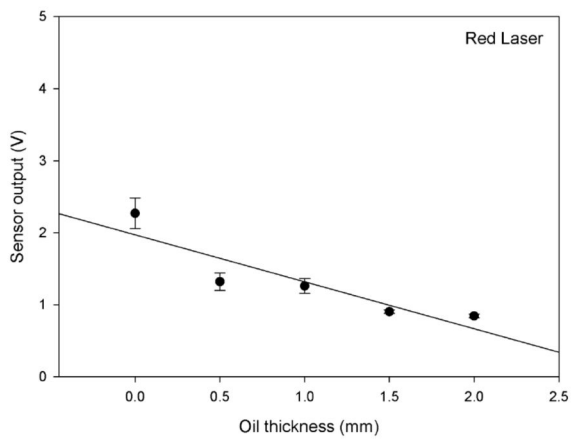


Figure 7. Sensor output results using a red laser in bunker C oil

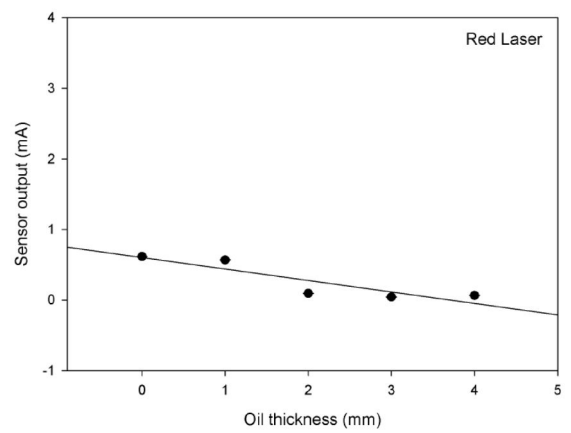


Figure 10. Sensor output results using a red laser in lubricating oil

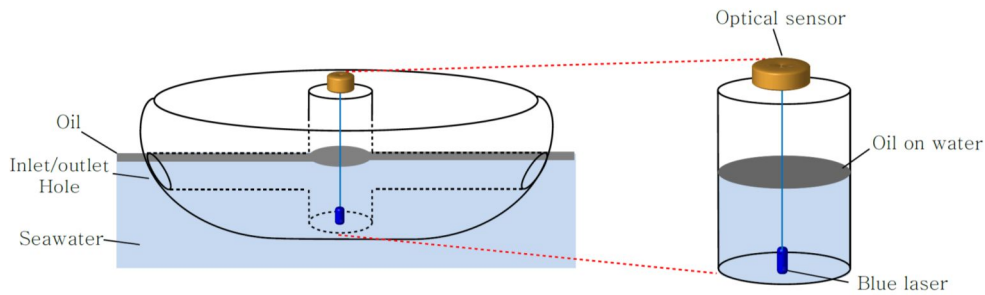


Figure 11. Schematic representation of the sensor platform

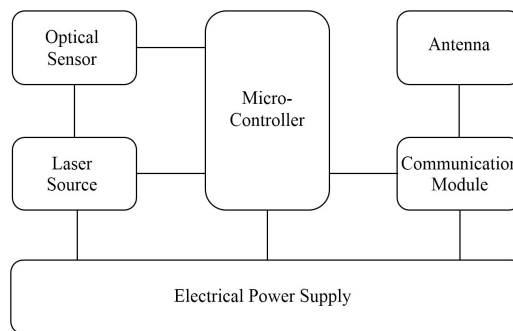


Figure 12. Schematic representation of the sensor architecture

#### D. Sensor Platform

For the future work, the sensor platform needs to be designed and manufactured in the form of the monitoring buoy. For effective detection on the sea surface, a dish-shaped floater is designed as a sensor platform; through two holes on the water-line side of the floater, the oil can enter and contact the optical detection part of the sensor (Fig. 11). The system architecture of the total sensor is shown in Fig. 12. It consists of the optical sensor, the laser source, the electrical power supply, the main controller and the communication part including the antenna.

### III. CONCLUSION

In this research, to find out the optimal wavelength laser, experiments using three lasers and two different oils were conducted and it was concluded that the blue laser was the optimal light source for the detection of oil presence and the measurement of oil thickness.

In this paper, a new optical oil detection methodology was proposed using the difference in light absorption between water and oil using the blue laser and the optical sensor.

### ACKNOWLEDGMENT

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