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EXAMINATION OF ADULTERATED COCONUT OIL BY FIBER OPTICS DISPLACEMENT SENSOR USING LATERAL OFFSET APPROACH

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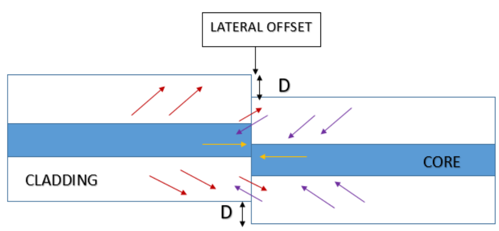
Graphical abstract



Abstract

A single-mode fiber (SMF) sensor for detecting coconut oil adulteration is proposed. Coconut oil is commonly used in cooking but health problems are caused by its adulteration. The lateral offset approach to the SMF-SMF displacement sensor was employed in this experiment to analyze the sensing responses of adulterant concentrations in coconut oil. The offset distances of the sensing probe were set at 6.47 µm, 11.57 µm, and 14.64 µm. Pure coconut oil, paraffin oil, and palm oil have an initial refractive index of 1.4481, 1.4585, and 1.4634, respectively. Upon completion, the highest sensitivity was observed at a lateral offset distance of 14.64 µm. These values were 0.286 dBm/mol for palm oil detection and 0.045 dBm/mol for paraffin oil detection. The findings of these experiments also showed that the larger the offset distance, the greater the sensitivity of the fiber sensor.

Keywords: Fiber optic sensor, oil adulteration, single-mode fiber, lateral offset, sensing device

Abstrak

Gentian optik mod tunggal (SMF) bagi pengesanan bendasing di dalam minyak kelapa dicadangkan. Minyak kelapa kerap digunakan di dalam masakan, bagaimanapun masalah kesihatan boleh terjadi akibat bendasing di dalamnya. Di dalam kerja-kerja pengujian, kaedah penderia anjakan SMF-SMF telah digunakan bagi menganalisa sambutan penderia terhadap kepekatan bendasing yang berbeza di dalam minyak kelapa. Minyak kelapa asli, minyak paraffin dan minyak sawit mempunyai indeks biasan 1.4481, 1.4585, dan 1.4634. Beza jajaran prob penderiaan ditetapkan pada 6.47 µm, 11.57 µm, dan 14.64 µm. Selesai pengujian di dapati beza jajaran 14.64 µm mempunyai sensitiviti yang tertinggi. Sensitiviti bagi pengesanan kehadiran minyak sawit di dalam minyak kelapa adalah 0.286 dBm/mol dan 0.045 dBm/mol bagi pengesanan minyak parafin. Hasil eksperimen juga mendapati, lebih besar jarak anjakan, lebih baik sensitiviti penderia optik.

Kata kunci: Penderia gentian optik, pencemaran minyak, gentian optik mod tunggal, teknologi optik, alat penderia

1.0 INTRODUCTION

Over recent decades, the use of optical fibers in communication and sensor technology has increased dramatically. In recent times, the use of fiber optics in sensor systems has received considerable attention due to the numerous advantages its offers, such as small in size and biologically neutral, while electric current is absent at the sensing point [1]–[4]. In the telecommunication industry, an optical fiber can be used as a modulator and a fiber optic sensor [5].

Lateral offset is a method of creating a core offset or core mismatch structure, which is achieved by splicing the joint of two fibers. The lateral offset fiber sensor structure has the advantages of easy control and flexible splicing. In 2018, Fangda Yu *et al*. [6] studied a large lateral core offset for RI sensing by enlarging the core-offset displacement from 6 to 40 µm. The study proved that RI was greater enhanced from 43.97 to 123.40 nm/RIU. In 2021, Yi Xu *et al*. [7] demonstrated salinity sensors using different lateral offset fusion splicing structures of SMF. This work obtained a good sensitivity measurement of 2.536 nm/percent, with 62.6 µm being the largest core offset obtained during the experiment. In 2013, Guolu Yin *et al*. [8] increased the RI sensitivity to 59.2 nm/RIU by proposing an asymmetrical fiber Mach–Zehnder interferometer by concatenating the single-mode abrupt taper and core-offset but without considering the direction.

Coconut oil has been applied in many applications including medicine, industry, and cookery. The most common coconut oil adulterants are paraffin oil, palm oil, and palm kernel oil [9]–[11]. Among these, paraffin oil and palm oil cause human health problems such as intestinal diseases, liver diseases, and even cancer [12]–[14]. Previous researchers have studied fiber sensors to identify coconut oil adulteration. In 2011, T.M. Libish *et al*. [12] developed a fiber optic sensor that used long-period grating to determine the adulteration of coconut oil by palm oil. The detection limit of this sensor was found to be 2% of coconut-palm oil adulteration. In 2010 [15], the same researcher demonstrated paraffin oil adulteration in coconut oil, also by using a long-period grating method. In this experiment, however, the detection limit was found to be 3% of coconut-paraffin oil adulteration. In 2005, M Sheeba *et al*. [16], using side-polished plastic optic fiber, devised and developed a method of detecting paraffin oil and palm oil adulteration in coconut oil. The intensity variation was found to be linear, and the detection limit was 2% paraffin oil/palm oil in coconut oil. In a previous work [17], the lateral offset technique was used with multi-mode fibers to detect the adulteration of coconut oil by paraffin oil and palm oil. The highest offset distance - a 7.83 µm fiber sensor - obtained the highest sensitivity of 0.406 dB/mol for palm oil detection and 0.437 dB/mol for paraffin oil detection.

In this work, a novel SMF optic sensor was developed, based on the lateral offset displacement for oil adulteration, by emphasizing the detection of paraffin oil and palm oil in coconut oil. The purpose of this study was to determine how the addition of paraffin oil and palm oil as adulterants affected the purity of coconut oil. As a result, the fiber was tilted, and the light-mode distribution at the lateral-offset fusion splicing junction was asymmetric, allowing significant power loss during transmission. High sensitivity levels of 0.286 dBm/mol and 0.045 dBm/mol were achieved for palm oil and paraffin oil, respectively.

2.0 METHODOLOGY

Figure 1 depicts the schematic diagram of the sensor probe development, based on the lateral displacement technique using the fusion splicing machine. Various structures, including waist expansion and lateral offset, can be developed by the fusion splicing approach. For this study, the sensor probe was designed with lateral offset (or lateral misalignment), which makes the major contribution to the overall loss in a fiber optic sensor [4], [18]. By this method, the light in the first fiber will leak into the cladding and exciting high cladding modes, while the second fiber will couple beams back to the core and form an interference pattern [19]. For this to happen, the end surfaces of the fiber optic cables were placed next to (or parallel to) one another [20]. If the cross-sections of the two fiber cores did not precisely overlap, an offset could cause power to be lost while transmitting light in the fiber. In sensor design, a defect in the connections reduces light transmission and is commonly used as the sensing region. Since the light from a lead-in fiber is dispersed throughout the core and cladding of the sensing fiber, the cladding modes interact to establish detection [21]. In this study, the offset displacement, D was varied to study the sensor's sensitivity as the displacement distance was increased.

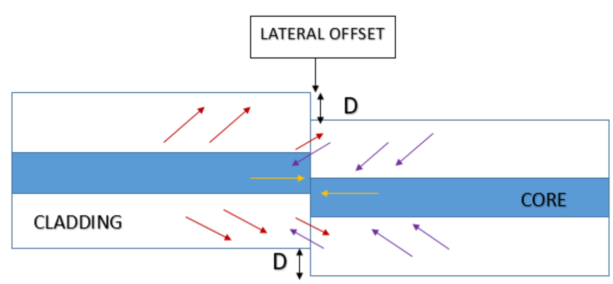


Figure 1 Lateral offset displacement, D for fiber probe using fusion splicing machine

Figure 2 shows the experimental setup, based on the SMF working around 1550 nm. The diameters of the SMF core and cladding were 10 µm and 125 µm, respectively. The fiber sensor head, or sensor probe, is a sensing component formed at the SMF center utilizing the previously mentioned lateral offset splicing technique. The study employed SMF, which prevents other modes of light from propagating. In addition, as light travels through the core, the number of reflections decreases, reducing the attenuation and increasing the signal range. The lateral offset distance was varied to ascertain how the misalignment gap affected sensor performance. The adulterated coconut oil samples were then prepared for adulterant testing by adding various amounts of paraffin oil and palm oil. The sensor's response to the optical signal loss was measured with an Optical Power Meter (OPM), which was attached to the sensor's lead-in fiber and used a light input source with a 1550 nm wavelength. A total of thirteen solutions were prepared to study the oil adulteration, including pure coconut oil, virgin palm oil, paraffin oil, five coconut-palm oil mixtures, and five coconut-paraffin oil mixtures. A sensor was tested on a refractometer to determine the initial refractive index (RI). In the fabrication of the sensing head, the Sumitomo type-36 fusion splicer was utilized to splice the fiber optic cables. The offset distance was altered to investigate four separate misalignments of 0 µm, 6.47 µm, 11.57 µm, and 14.64 µm.

Five samples were prepared using different mixture of coconut and palm oil as in Table 1. Similarly, for the coconut-paraffin oil mixture, the coconut oil was diluted using the paraffin proportions in Table 2. from which 0.0286 mol/g, 0.0273 mol/g, 0.0262 mol/g, 0.0227 mol/g, and 0.0213mol/g concentrations were obtained, respectively. The initial refractive index values of three different oils - pure coconut, paraffin, and palm - were obtained using a digital refractometer.

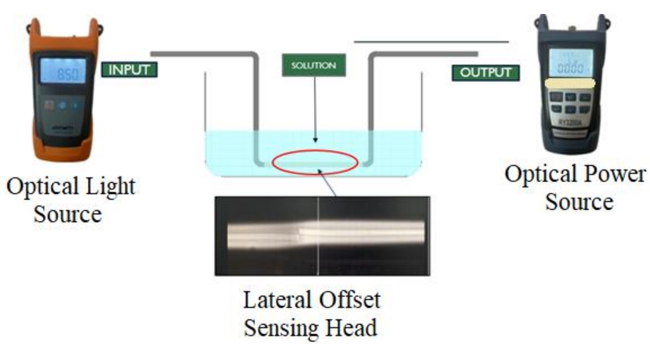


Figure 2 Experimental setup for adulteration sensing.

Table 1 Five coconut/palm oil samples preparation

Coconut/palm oil %	Mole content (mol/g
95/5	0.019
87/13	0.018
80/20	0.017
71/29	0.016
66/34	0.015

Table 2 Five coconut/paraffin oil samples preparation

Coconut/paraffin oil %	Mole content (mol/g
95/5	0.0286
87/13	0.0273
80/20	0.0262
71/29	0.0227
66/34	0.0213

3.0 RESULTS AND DISCUSSION

All the fiber sensors were fixed at one meter in length. Figures 3, 4, and 5 show images of the spliced offset segments from the splicing machine, as recorded by the Axioskop 2 MAT Image Analyzer.

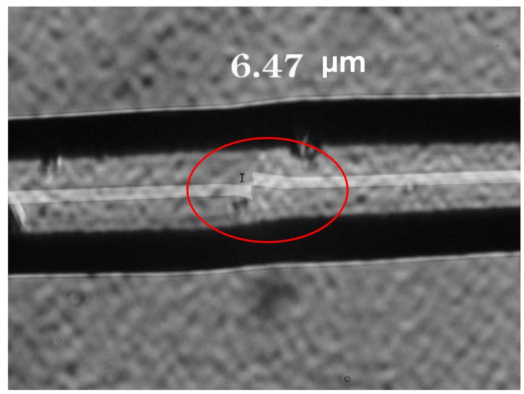


Figure 3 Recorded Image from Image Analyzer for 6.47 µm lateral offset

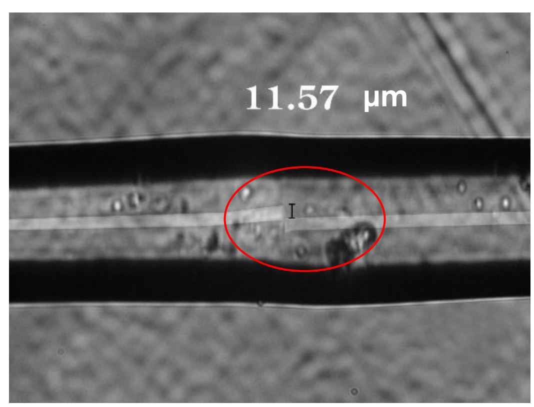


Figure 4 Recorded Image from Image Analyzer for 11.57 µm lateral offset

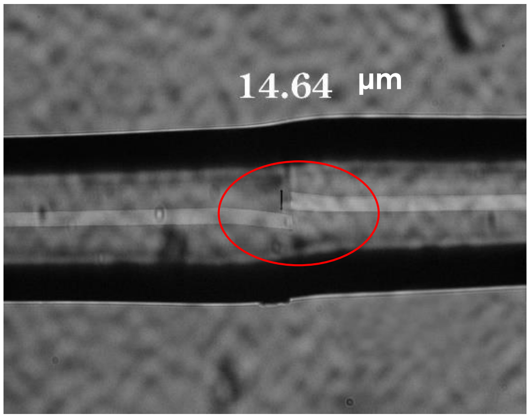


Figure 5 Recorded Image from Image Analyzer for 14.64 µm lateral offset

Figure 6 depicts the refractive index values for various oil combination concentrations of the coconut-palm oil and coconut-paraffin oil mixtures, based on the volume of adulterants added to the coconut oil. The initial offset was set to 0 µm. The RI increased in proportion to the amount of adulterants present. Pure coconut oil has a refractive index of 1.4481. Adding adulterants to coconut oil altered the RI value of the mixture. Furthermore, the graph shows that the slope of the refractive index of palm oil with coconut oil is steeper than the slope of the refractive index for coconut oil with paraffin oil because palm oil has similar physical and chemical properties to coconut oil and blends in a similar way to coconut oil [22]. The slope of the line reflects the fiber's sensitivity when interacting with specific aqueous solutions. The steeper the slope, the greater the sensitivity of the fiber sensor. As the graph indicates, the sensitivity of palm oil is 0.9 µRIU/ percent and that of paraffin oil is 0.6 µRIU/ percent.

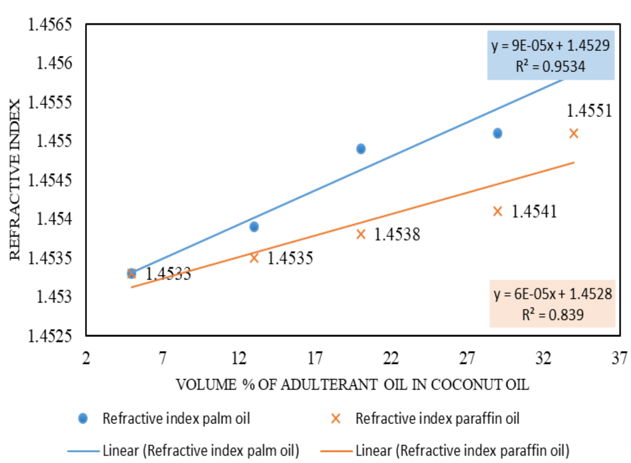


Figure 6 Refractive Index (RIU) vs volume of palm oil/paraffin oil in coconut oil

The result was validated by the work of Sheeba *et al*. [9], whose data displayed similar patterns. The current study revealed that as the quantity of adulterants grows, the refractive index of the medium surrounding the sensor head also increases; however, the output intensity drops. This is also consistent with the Clausius-Mosetti equation, which states that as the RI increases, the output power decreases [23].

(a) Analysis of Coconut Oil Adulteration due to Palm Oil

To investigate the effect of coconut oil adulteration caused by the presence of palm oil, five mixtures of different concentrations were tested: 0.019 mol/g, 0.018 mol/g, 0.016 mol/g, 0.015 mol/g, and 0.014 mol/g. These were prepared with coconut-palm oil volume percentage ratios of 95/5, 87/13, 80/20, 71/29, and 66/34, respectively. The offset distance was varied, and the output power was measured and summarized, as shown in Table 1. The findings demonstrate that a larger offset gap will produces a higher power loss. For the 14.64 µm offset, the output power for 66% coconut oil mixed with 34% palm oil with the number of moles at 0.014 mol/g experienced a -22.92 dBm loss, compared to a -18.03 dBm loss for the 6.47 µm offset at the same number of moles. To summarize, the greater the volume of adulterant oil in coconut oil, the greater the output loss.

Table 1 Output power for coconut/palm oil mixture with 0 µm, 6.47 µm, 11.57 µm, and 14.64 µm lateral offset

	Power (dBm)			
Number of moles (mol) /Lateral offset (µm)	**0**	**6.47**	**11.57**	**14.64**
0.019	-8.06	-17.75	-20.86	-21.9
0.018	-8.14	-17.72	-20.85	-22.04
0.016	-8.34	-17.7	-20.89	-22.72
0.015	-8.38	-17.94	-21.18	-22.86
0.014	-8.64	-18.03	-21.25	-22.92

Figure 7 portrays the power output (dBm) versus the number of moles (mol) for the coconut-palm oil mixture (calculated based on the percentage of coconut-palm oil volume). For the 0 µm, 6.47 µm, 11.57 µm, and 14.64 µm offsets, the sensitivity levels were 0.14 dBm/mol, 0.078 dBm/mol, 0.111 dBm/mol, and 0.286 dBm/mol, respectively. The results also show that for the same adulterant volume, the output intensity decreased linearly as the lateral offset increased. The output power loss clearly shows that the wider the lateral distance, the greater the output power loss. The sensitivity was also increases as the offset widen.

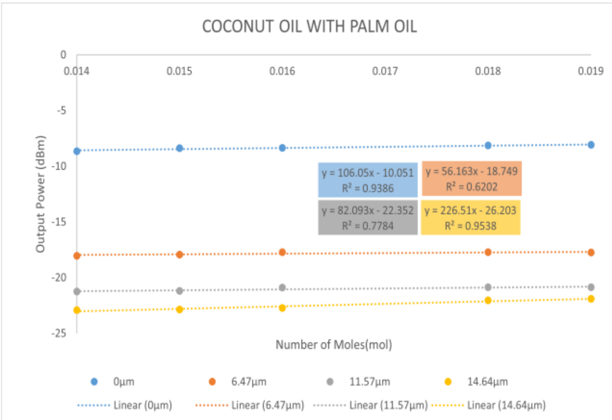


Figure 7 Graph of output power (dBm) vs the number of moles (mol) of coconut –palm oil mixture for various lateral offset distances

(b) Analysis of Coconut Oil Adulteration due to Paraffin Oil

For coconut oil adulteration due to paraffin oil contamination, five samples were prepared, as listed in Table 2. The volume percentage ratios for these coconut/paraffin oil mixtures were 95/5, 87/13, 80/20, 71/29, and 66/34, with mole concentrations of 0.0286 mol, 0.0273 mol, 0.0262mol, 0.0227 mol, and 0.0213 mol, respectively.

Table 2 Output power for coconut/paraffin oil mixture with 0 µm, 6.47 µm, 11.57 µm, and 14.64 µm lateral offset

	Power (dBm)			
Number of moles (mol) / Lateral offset (µm)	**0**	**6.47**	**11.57**	**14.64**
0.0286	-8.83	-18.09	-20.49	-21.95
0.0273	-8.88	-18.11	-20.82	-22.04
0.0262	-8.92	-18.18	-20.85	-22.08
0.0227	-8.94	-18.2	-20.93	-22.11
0.0213	-8.97	-18.22	-21.07	-22.14

Table 2 tabulates the measured output power for the coconut/paraffin oil mixture with four different lateral offsets. Similarly, it can be seen that a larger lateral offset produced a greater power loss; for example, the power received was -22.14 dBm rather than -8.97 dBm with no lateral offset, as observed for 0.0213 mol/µm. It is also worth noting that as the number of moles increased, the power received decreased with the same lateral offset. Hence, the higher the percentage of paraffin oil in coconut oil, the greater the output loss.

Figure 8 depicts the relationship between the output power (dBm) and the number of moles (mol) within the coconut-paraffin oil mixture for various lateral offsets. The sensitivity levels obtained for 0 µm, 6.47 µm, 11.57 µm, and 14.64 µm were 0.034 dBm/mol, 0.035 dBm/mol, 0.127 dBm/mol, and 0.045 dBm/mol, respectively. It is clear that while the sensor's sensitivity increased, the maximum output power decreased. Hence, a larger offset distance gap increased the sensor's sensitivity, as proven by the analyses of the coconut-palm oil mixture. These results were consistent with the theoretical concept, whereby the study explained that as the misalignment between two fibers increased, the light entering the cladding rose steadily. As a result, the fibers lost energy at a faster rate. The greater the amount of light entering the sensing area, the better the sensor's capacity to detect changes in the surrounding materials [24]. The results show that enlarging the lateral offset could improve the sensitivity of the designed sensor.

Figures 7 and 8 show that the sensor's sensitivity in detecting paraffin oil was higher than it was for detecting palm oil. This is because palm oil has similar properties to coconut oil and blends easily. As a result, detecting adulteration becomes difficult, particularly when the adulterant has similar chemical properties to the original oil [14].

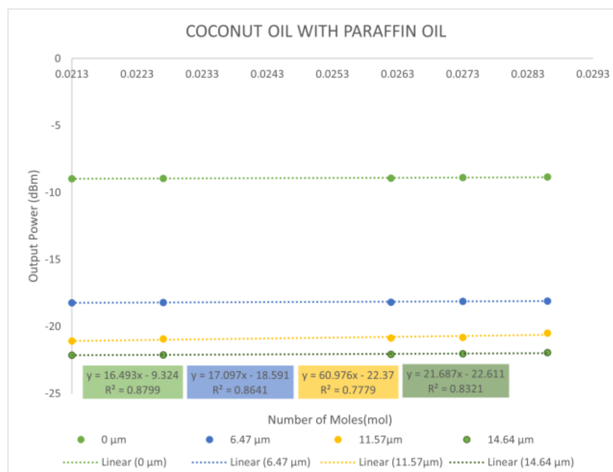


Figure 8 Graph of output power (dBm) versus the number of moles (mol) coconut oil with paraffin oil by using SMF

4.0 CONCLUSION

In this study, we developed and tested a simple, small, and highly sensitive fiber sensor, based on the lateral displacement technique. Two different types of adulterant oils, which is palm oil and paraffin oil, were used to test the sensor device's responses to coconut oil adulteration. Larger offset produces higher sensitivity paraffin and palm oil adulteration sensor. It was also observed from the sensor's performance that the detection of paraffin oil adultery demonstrated higher sensitivity as compare to palm oil. For the 14.64 µm offset, the sensitivity levels for palm oil and paraffin oil detection were 0.286 dBm/mol and 0.045 dBm/mol, respectively. The proposed sensor is a low-cost option for solution measurement, high-sensitivity, simple, and easy fabrication techniques.

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