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Determining Stingless Bee Honey Adulteration with Cane Sugar using Fiber Optic Lateral Offset Method

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Abstract

This study aims to lay the groundwork for utilizing a fiber optic lateral offset system to detect adulteration in stingless bee honey, addressing the limited research available on this technique. The focus is to design and test the fiber optic lateral offset system, evaluate its performance with honey samples of varying purity levels, and analyse its effectiveness in detecting adulteration. Tests were conducted using cane sugar-adulterated honey samples at offset distances ranging from 0.0 µm to 5.5 µm. The system demonstrated promising sensitivity, achieving the highest accuracy at a 0.0 µm offset (-1.467 dBm/mol) and reliable performance at larger offsets, such as -1.193 dBm/mol at 5.5 µm. Compared to refractometer measurements, the fiber optic system proved more effective in identifying subtle adulteration. This study serves as a foundation for developing cost-effective, real-time, and portable sensors for honey quality assurance and broader food authenticity applications.

1. Introduction

Stingless bee honey, known as meliponine honey, has a unique taste, high nutritional value, and medicinal benefits [1]. However, its popularity has resulted in widespread adulteration, where substances like glucose syrup and water are added to increase quantity at the cost of quality [2,3]. This reduces its benefits and poses health risks, especially for diabetic individuals, as the added sugars can worsen their condition [4]. In Malaysia, up to 80% of honey is reported to be adulterated, affecting consumer trust and leading to economic losses for producers and buyers alike [4].

Conventional methods like High-Performance Liquid Chromatography (HPLC) and Fourier-Transform Infrared Spectroscopy (FTIR) are precise but have several drawbacks [5,6]. They are expensive, take time, and need trained specialists [7]. Because of these challenges, there is a need for simpler, quicker, and more affordable techniques. Fiber optic sensors, which use the lateral offset principle to detect changes, offer a promising alternative [8]. The lateral offset method measures how much light is lost when it moves between two slightly misaligned optical fibers. When the fibers are perfectly lined up, most of the light passes through with little loss. But if one fiber is shifted to the side, some light escapes, and less reaches the other fiber[8,10]. These sensors are already widely used in various applications, such as measuring ethanol concentration, sucrose, glucose, sodium chloride solutions, preservatives in milk, and detecting adulterants in edible oils [9-13]. These sensors can measure how light changes when it passes through honey, making them a practical tool for detecting adulteration [9]. This study tests how well this system works to identify impurities in stingless bee honey.

2. Materials and Methods

2.1 Sample Preparation

Honey samples were prepared by diluting pure stingless bee honey with cane sugar solutions to simulate varying levels of adulteration. Seven purity levels (100%, 95%, 90%, 80%, 50%, and 30%) were tested, with a total volume of 20 mL for each sample. The cane sugar concentration in the solutions varied accordingly to achieve the desired purity levels. For instance, the 100% purity sample contained only honey, while the 30% purity sample included 14 mL of cane sugar solution and 6 mL of honey. Each solution was thoroughly mixed to ensure even distribution and consistency.

The cane sugar solution is 0.555 mol/L, and the average mole concentration of stingless bee honey is approximately 5.6 mol/L, the sample mixture volume is 20 mL. The cane sugar solution and honey volume can be determined based on the sample's purity percentage. Then we add the moles of cane sugar and the moles of honey to get the total moles in the sample as shown in the data in Table 1.

2.2 Experiment Setup

The fiber optic lateral offset system was configured with offset distances of 0.0 µm, 1.5 µm, 2.5 µm, 3.5 µm, and 5.5 µm, as illustrated in the accompanying Fig. 1. This figure demonstrates the concept of lateral offset, showing how light alignment between two optical fibers is intentionally shifted to create varying degrees of displacement.

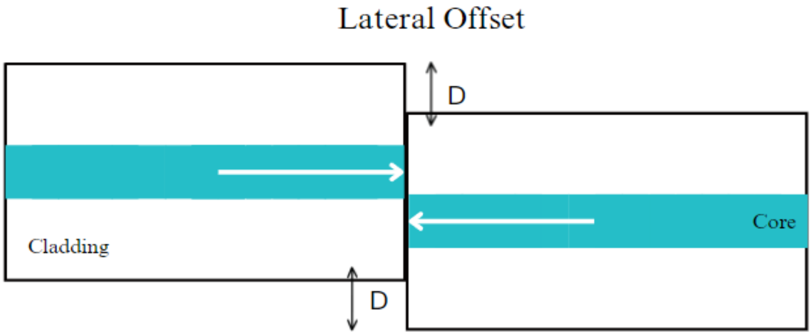


Fig. 1 Schematic Diagram of Lateral Offset

The fiber optic system is configured by splicing the optical fibers with different lateral offset distances (0.0 µm, 1.5 µm, 2.5 µm, 3.5 µm, and 5.5 µm. The setup involves connecting the system to an optical light source and an optical power meter. Each honey sample is placed on the lateral offset platform, as illustrated in Fig. 2. The optical power meter records the transmitted light intensity for each sample at varying offset distances. These measurements provide insights into the interaction between the honey samples and the optical fiber system.

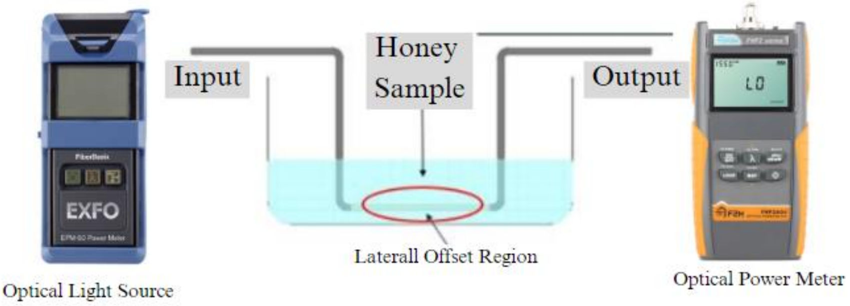
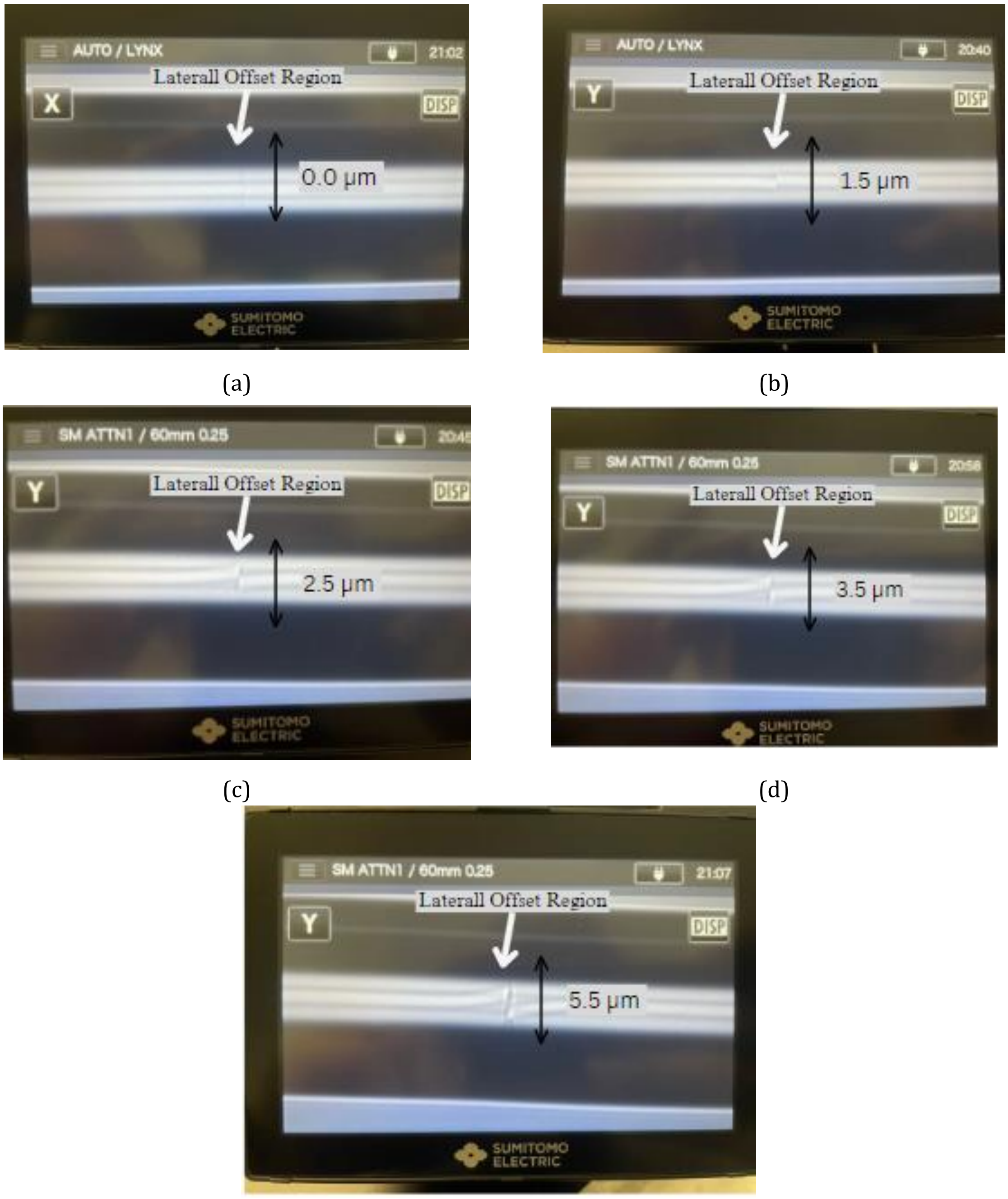


Fig. 2 Fiber Optic Lateral Offset Setup

3. Result and Discussion

The splice region as shown in Fig. 3 exhibits a lateral offset deviation of from 0.0 µm to 5.5 µm when exposed to adulterated honey samples. This deviation is attributed to differences in the optical properties of pure honey versus cane sugar solutions. The sensor utilizes a splice region as a critical detection point.



(a) (b)

(c) (d)

(e)

Fig. 3 0. 0 µm (a), 1.5 µm (b), 2.5 µm (c), 3.5 µm (d), and 5.5 µm (e)

3.1 Refractive Index Measurements

Fig. 4 presents the refractive index value of stingless bee honey adulterated with varying concentrations of cane sugar. The study observed that RI increased as the percentage of cane sugar in the honey mixture increased. Pure stingless bee honey exhibited an RI of 1.49 and this value progressively increased with the addition of cane sugar.

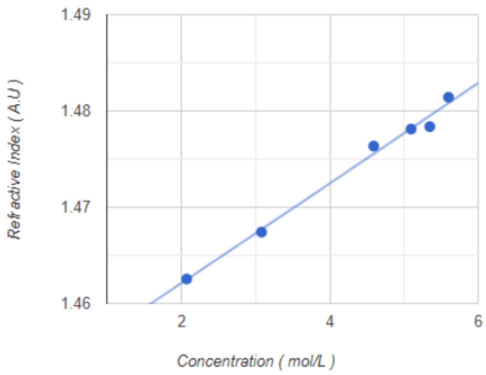


Fig. 4 Refractive Index versus Concentration Graph

3.2 Fiber Optic Lateral Offset Analysis

Fig. 5 illustrates the power loss of the fiber optic sensor at various lateral offset distances (0.0 μm to 5.5 μm) across a range of concentrations (2.0685 mol/L to 5.6 mol/L). The results show a consistent power loss increase with higher lateral offsets and increasing concentration values.

At a 0.0 μm offset, the power loss remains minimal across all concentrations, indicating negligible attenuation due to the precise alignment of the fiber cores. However, as the offset distance increases, the power loss becomes more pronounced, with the most substantial attenuation observed at the 5.5 μm offset. For example, at the highest concentration of 5.6 mol/L, the power loss reaches approximately -3.07 dBm at 5.5 μm, compared to -0.55 dBm at 0.0 μm. This demonstrates that larger offsets enhance the system's sensitivity, amplifying the ability to detect changes in the sample's optical properties.

The observed trend can be attributed to increased lateral displacement, which disrupts the optical signal and enhances light scattering and absorption within the sample. These changes are more prominent at higher concentrations, where variations in refractive index become significant. The data aligns with previous studies [15–17], highlighting the effectiveness of fiber optic sensors in detecting purity variations by measuring refractive index and light scattering.

The results confirm that larger lateral offsets improve the sensor's ability to detect subtle differences in sample concentration, making it a viable approach for applications such as honey adulteration detection. This sensitivity to minor changes supports the fiber optic system's potential for quality assurance in food and other industries.

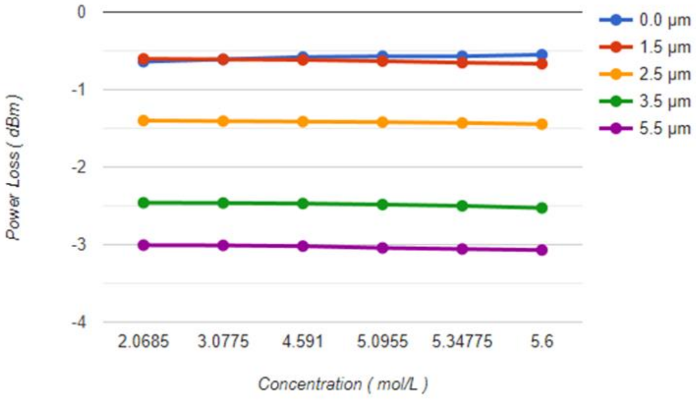


Fig. 5 Refractive Index versus Concentration Graph

Fig. 6 presents the sensitivity of the fiber optic sensor (in dBm/mol) as a function of lateral offset distance (μm). The results demonstrate a distinct trend, where the sensitivity initially increases with the lateral offset, reaching a peak at approximately 2.5 μm before gradually declining at larger offsets. The sensitivity was evaluated by measuring the change in optical power (dBm) at each offset distance across honey samples with varying purity levels. The gradient of the power attenuation versus concentration graph was used to calculate the sensitivity of the sensor, representing its responsiveness to changes in the sample's refractive index or concentration.

The observed peak sensitivity at 2.5 µm indicates an optimal lateral offset for maximizing the sensor's responsiveness. This behaviour is attributed to a balance between sufficient light coupling and effective interaction of the optical signal with the medium. At smaller offsets, sensitivity is limited due to minimal scattering and negligible disruption to the transmitted light. Conversely, excessive scattering and light loss at larger offsets reduce sensitivity, as a significant portion of the optical signal is attenuated before it interacts effectively with the medium.

These findings are consistent with earlier studies on lateral displacement in fiber optic sensors, which highlight that an optimal offset enhances the sensor's ability to detect small changes in refractive index or concentration by increasing the interaction of light with the sample [9,14]. Beyond this optimal range, sensitivity declines due to excessive signal loss, reducing the accuracy of measurements. The results emphasize the importance of the experimental setup, particularly the preparation of honey samples with different purity levels, precise alignment of the fiber optic system, and the use of gradients from the graphs to evaluate sensitivity accurately.

The results reinforce the potential of lateral offset adjustment as a critical parameter in optimizing fiber optic sensors for various applications, such as detecting adulteration in liquid food products or monitoring chemical concentrations. The identification of an optimal offset ensures high sensitivity, making the system highly effective for quality control and environmental monitoring [8,12].

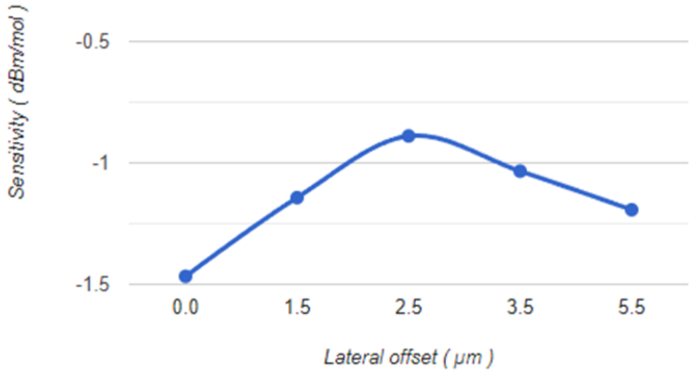


Fig. 6 Offset Sensitivity

4. Conclusion

The study successfully set up and tested a fiber optic lateral offset system for detecting adulteration in stingless bee honey. By characterizing the lateral offset technique across different purity levels, the system demonstrated its capability to analyses performance with high sensitivity. Sensitivity values ranged from -1.467 dBm/mol at 0.0 µm to -0.889 dBm/mol at 2.5 µm, showcasing the system's effectiveness in identifying subtle changes in purity. Its advantages include real-time analysis, cost-effectiveness, and ease of use, making it suitable for both small-scale producers and large-scale quality assurance. Future work could explore integrating this system into portable devices for widespread application.

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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: ***study conception and design:*** *Muhammad Wahyu Harun;* ***solve the governing equation:*** *Muhammad Wahyu Harun, Nurul Nadia Adnan;* ***data collection:*** *Muhammad Wahyu Harun;* ***analysis and interpretation of results:*** *Muhammad Wahyu Harun, Nurul Nadia Adnan, Nurul Ain Mohd Yusoff Shah;* ***draft manuscript preparation:*** *Muhammad Wahyu Harun, Nurul Nadia Adnan, Nurul Ain Mohd Yusoff Shah. All authors reviewed the results and approved the final version of the manuscript.*

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