Empirical Modelling of Household Oils in UV-Vis-NIR Spectrum through Developed Low-Cost Spectroscopy Setup (LCSS)

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Empirical Modelling of Household Oils in UV-Vis-NIR Spectrum through Developed Low-Cost Spectroscopy Setup (LCSS)

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Abstract: In this research work, a low-cost UV − Vis − NIR spectroscopy setup (LCSS) is developed and presented to analyze transmission (%) and absorption (Au) from household oils samples. The sensing potential of the developed setup is examined using four different oil samples. These oil samples consist of olive oil, mustard oil, amla oil, and red palm oil. The transmission (%) obtained for olive oil, mustard oil, amla oil, and red palm oil is 75.66%, 71.10%, 69.87%, and 68.12% at 923.2 nm, 924.5 nm, 925.9 nm, and 927.8 nm respectively. Similarly, the absorbance (Au) for olive oil, mustard oil, amla oil, and red palm oil is 0.121 Au, 0.141 Au, 0.153 Au, and 0.163 Au at 920.0 nm, 923.0 nm, 925.8 nm, and 930.2 nm respectively. A linear relationship in the wavelength range of 920 nm to 935 nm between transmission (%) and wavelength produce $R^2 = 0.9717$ corresponding to a degree (2). Similarly, the linear relation between absorbance (Au) and wavelength produce $R^2 = 0.9997$ corresponding to a degree (2). Finally, an 8th order empirical sinusoidal model is developed for transmission (%) and absorbance (Au) corresponding to the olive oil, mustard oil, amla oil, and red palm oil. The maximum value of $R^−square$ corresponding to the transmission (%) for the developed empirical model is obtained for amla oil. Similarly, the full value of the absorbance (Au) from the developed empirical model is obtained for red palm oil, which indicates a great response towards the empirical sinusoidal model.

Keywords: LCSS, transmission, absorbance, olive oil, mustard oil, amla oil, red palm oil.

1. Introduction

Several sensing setups and spectroscopes developed to date to analyze liquids, biochemical, bioanalytes, etc., based on transmission (%) and absorbance (Au). Some of the prominent sensing setups developed in optical physics consist of “curvature sensing setup” based on fiber laser and gratings [1], “displacement and curvature sensing setup” based on the “Fabry–Perot interferometer” [2], sensing setup to identify the amount of torsion based on a “three-beam path Mach–Zehnder interferometer” [3] and so on. In this research, a novel low-cost spectroscopy setup (LCSS) is developed and presented inspired by traditional spectroscopy devices. The developed setup identifies the behavior light entering and leaving the sample solution. The light
transmitted by the sample solution is known as “transmission.” The amount of light absorbed by the sample solution is known as the “absorbance” of the sample solution. The sample solutions investigated in this research work are common household oils used in most kitchens all around the World. The sample household oils consist of olive oil, mustard oil, amla oil, and red palm oil. These oil samples consist of different chemical compositions thus have distinct behavior corresponding to light of 200 nm to 1200 nm. Analyzing the transmission and absorbance from the oils sample assists in identifying the concentration of different oils, which can be used as a “new standard for quality evaluation” of the household oils.

In the last few decades use of photonic devices in optical communication setups, biosensing apparatus, wavelength division multiplexing (WDM), spectroscopy analysis, physical parameter sensing [4] [5], etc., have tremendously increased. Among the above applications, fiber lasers are extensively used for physical parameter sensing. The sensing setup through which the interaction of light with a sample is analyzed mainly depends on its photophysical properties. Today several biosensing setups have developed, like fluorescent sensors [6], electrochemiluminescence sensors [7], dynamic light scattering sensors [8], surface-enhanced Raman scattering sensors [9], colorimetric sensors [10], and surface plasmon resonance sensors [11], [12]. The primary principle of these sensing devices is the “light” and “sample” interaction.

The proposed setup is designed to operate in $UV – Vis – NIR$ range. The $UV$ region lies in the wavelength range of 10 nm – 400 nm [13]. This range can be further divided into three different bands, i.e., $UVA$ (315 nm – 400 nm), $UVB$ (280 nm – 315 nm) and $UVC$ (100 nm – 280 nm) [14]. The range of the visible spectrum is 400 nm – 700 nm approximately [15]. Finally, the wavelength range of the $NIR$ spectrum lies in the interval 750 nm to 2500 nm [16] Since the proposed spectroscope is designed to operate in the wavelength range of 200 nm – 1200 nm, thus its operational range lie in the $UV – Vis – NIR$ region.

Spectroscopes designed in the $UV – Vis – NIR$ range can determine the spectral properties of liquids and solids in a wide range. These devices can quantify the amount of analytes present in a solution. These devices provide “quality control” and “quality assurance.” The spectroscopes working in $UV – Vis – NIR$ range possess some advantages and shortcomings.

**Advantages of spectroscopes designed in the $UV – Vis – NIR$ range.**

- The concentration of a wide variety of analytes in a solution can be examined in this wavelength range.
Analytes quantification in a solution using this UV – Vis – NIR spectroscopy technique is less time-consuming and easier than chromatographic analysis.

Shortcoming of spectroscopes designed in the UV – Vis – NIR range

- Unwanted components in a solution can affect the sensing process.
- Methods based on chromatographic analysis have shown more accuracy and preciseness as compared to UV – Vis – NIR spectroscopy.
- Selection of sample size, sample volume has their specific requirement and challenges.

The article is organized into four sections. Section (2) presents the background principle of calculating transmission and absorbance from the liquids samples. Section (3) offers the details of the developed LCSS and experimental results. Finally, section (4) presents the concluding remarks on the research work.

2. Background principle of the proposed LCSS

Beer lambert law states that when monochromatic light is passed through a sample solution, the rate of decrease in the intensity with the thickness of the medium is proportional to the intensity of the light. In optics, quantification of the photons numbers delivered at a particular point at some specific time interval is known as “light intensity.” In ordinary perception, “bright light” corresponds to the high intensity of light, and “dimmer light” corresponds to light having low intensity [17]. If the light beam of intensity ($I_i n$) is entering the sample and the light beam of intensity ($I_o u t$) is leaving the sample [18]. The relation of change in the light intensity concerning the path length of the sample holder is expressed by Equation (1 – 9).

$$-\frac{dI}{dl} \propto I$$ (1)

$$-\frac{dI}{dl} = \alpha I$$ (2)

$$-\frac{dI}{l} = \alpha dl$$ (3)

$$-\int_{I_{out}}^{I_{in}} \frac{dl}{I} = \int \alpha dl$$ (4)

$$-[log(I)]_{I_{out}}^{I_{in}} = \alpha L$$ (5)

$$log(I_{in}) - log(I_{out}) = -\alpha L$$ (6)

$$log\left(\frac{I_{in}}{I_{out}}\right) = -\alpha L$$ (7)
\[
\left( \frac{I_{in}}{I_{out}} \right) = e^{-\alpha L} \quad (8)
\]
\[
I_{in} = I_{out} e^{-\alpha L} \quad (9)
\]

The phenomenon of the incoming and outgoing light flow from the sample solution can be understood from Figure (1). Thus, the ratio of light “entering” the sample and light “leaving” the sample is defined as “Transmission.” It can be expressed by Equation (10). It is a unitless quantity [19].

\[
Transmission = \left( \frac{I_{in}}{I_{out}} \right) \text{[Unitless]} \quad (10)
\]

The transmission in percentage is expressed by Equation (11) [5].

\[
Transmission (\%) = \left( \frac{I_{in}}{I_{out}} \right) \times 100 \quad (11)
\]

Indeed, the amount of light leaving the sample will have a low intensity than the intensity of light entering the sample. Thus the amount of light lost in between entering and leaving the sample is known as the “absorbance” of the sample solution. It is assigned a unit (Au) known as an arbitrary unit. Different sample solutions can have different absorbance values. It is expressed by Equation (12) [20].

\[
Absorbance (Ab) = -\log_{10} \left( \frac{I_{in}}{I_{out}} \right) \text{[Au]} \quad (12)
\]

When a light beam of a convenient wavelength (nm) is passed through some dilute solution, the light photons absorbed by the solution will be small, but certainly, some light photons will be absorbed. This results in “high transmission” and “low absorbance.” Similarly, when a light beam is passed through a concentrated solution. The number of photons absorbed will be high as compared to the dilute solution. Thus, in this case, “low transmission” and “high absorbance” are recorded. Therefore “transmission” and “absorbance” both depend upon the concentration of the sample solution.

Absorbance is also related to the “length of the path” in which the sample solution is present. It is expressed by Equation (13) [21].

\[
Absorbance = k_l \times p_l \times c \quad (13)
\]

Where \( k_l \) is the constant of proportionality, \( p_l \) is defined as the path’s length, and “c” is the solution’s concentration under investigation. This technique is an adaption of the “Beer-Lambert Law” [22].

The pictorial representation of the sensing methodology for the proposed LCSS is presented in Figure (1). The amount of light leaving the light source is \( I_{in} \) which travel through an optical
fiber to the sample holder. The amount of light leaving is sample holder is $I_{out}$ which is measured through a spectrometer and is presented on the computer screen as output. While performing the practical experimentation, it is essential to note that atmospheric disturbance always affects the sensing process. Therefore, the transmission and absorbance parameters are likewise affected, and thus the modified transmission and absorbance are expressed by Equation (14) and Equation (15).

Transmission ($\%$) = \( \frac{I_{in} - I_{Dark}}{I_{out} - I_{Dark}} \)  

(14)

Absorbance ($Ab$) = \(-\log_{10}\frac{I_{in}-I_{Dark}}{I_{out}-I_{Dark}}\)  

(15)

Where $I_{Dark}$ is the atmospheric disturbance generated during the sample testing process, which is extracted from the experimental method.

![Block diagram](image)

Figure 1: Block diagram for analyzing transmission and absorbance from the sample

3. Experimental Results

The LCSS presented in this research work measures the incoming and outgoing light through the sample. This sample can be water, fluid, chemicals, anything but in liquid form. The LCSS main components are halogen light source, sample compartment, sample cuvettes, spectrometer, and connecting optical fiber. The output received from the spectrometer is transferred to the computer screen using a USB cable. The light source is a “stabilized tungsten halogen light source” which can operate in the wavelength range of 360 – 2600 nm. Its operational temperature is 4.5°C to 35°C. The sample compartment is a black-colored solid metallic chamber that prevents the sample from atmospheric disturbances and interferences.
The sample holder is a hollow cuboidal tube made up of quartz material. The cuvette is having a 10 mm path length and has a volume of 3500 µl. It is having a dimension of 45 mm × 12.5 mm × 12.5 mm. While analyzing a sample solution, it is essential to note that the cuvette should be filled minimum of up to 50 µl the for correct reading. The cuvette needs to be rinsed with the distilled water every time after a sample is analyzed. The spectrometer is a “charge-coupled device (CCD)” having a linear array detector with 3648 pixels. It can operate with a total capacity up to 0.03 nm “full-wave half maximum (FWHM). The spectrometer system consists of a focusing optical system, dispersion element (grating), collimating mirror, incident slit, and a detector. All the components are connected with the assistance of optical fiber. The light is passed into the spectrometer device through the optical fiber. Lastly, a USB cable is connected with a computer system in which the data from the spectrometer is received after analyzing sample solutions. Finally, the spectral information collected is represented in transmission (%) and absorbance (Au) corresponding to the different oil samples. In this case, different oil samples are analyzed from the setup. The components of the developed LCSS consist of a halogen light source, sample compartment, sample holder, and spectrometer purchased from “Research India” Bhopal, India [23]. The optical fiber cable used in the proposed LCSS is M93L01 stainless steel fiber patch cable purchased from the “THOR lab” New Jersey, United States [24]. Finally, the oil samples used in this work are obtained from the local vendors of the Longowal, Punjab, India [25]. The oils investigated through the sensing setup includes olive oil, mustard oil, amla oil, and red palm oil, as presented in Figure 2 (b).
Oil sample (1) is olive oil presented in Figure 2 (b-i), in which contamination is externally added in many forms like the mixing of refined vegetable oils (dilution), the addition of coloring additive (unauthorized enhancement), mixing deep-fried used oil [26]. These contaminations affect the concentration of olive oil. Oil sample (2) consists of mustard oil presented in Figure 2 (b-ii). It is reddish-brown or amber in color. Mustard oil is the main component of the Indian kitchen. Adulteration in mustard oil with fried mustard oil causes a potential threat to the health of the consumers. The fried mustard oil consists of polyunsaturated fatty acids, which affect the concentration of the mustard oil [27]. Oil sample (3) consists of amla oil presented in Figure 2 (b-iii). This oil is dark green. Amla is popularly known as Indian gooseberry. It is classified in various categories as native gooseberry, wild gooseberry, etc. Cape gooseberry is a fruit that is having high demand throughout the World. Amla oil is also degraded by various chemicals and additives, which affect the oil sample concentration [28]. Oil sample (4) is presented in Figure 2 (b-iv), which consists of red palm oil that is very nutritious. In many research, it has been proved that it has similar qualities to milk. It is considered a good supplement for pregnant women. There are several methods through which red palm oil is adulterated. At the same time, this oil is also used as an adulteration agent. Thus the concentration of the red palm is degraded by various methods and toxic substances [29].

A. Analysis of the spectral behavior of the oil sample

The spectral behavior of the transmission (%) and absorbance (Au) from different household oil samples is analyzed from the developed LCSS.
Figure 3 (a) Transmission (%) corresponding to different oil samples (b) Absorbance (Au) corresponding to different oil samples

Figure (3) presents the outcome of the spectroscopy analysis of olive oil, mustard oil, amla oil, and red palm oil samples for the wavelength range of 200 nm to 1200 nm. It can be observed from Figure 3 (a) that all four oil samples are responding differently under the same conditions. Olive oil has obtained a transmission (%) of 11.58%, 82.35%, 75.66%, and 78.77% at a wavelength of 357.9 nm, 758.7 nm, 923.2 nm, and 1020 nm respectively. Transmission (%) of 0.5851%, 73.29%, 64.37%, and 71.10% is obtained at the wavelength of 471.8 nm, 592.6 nm, 666.2 nm, and 925.5 nm respectively corresponding to the mustard oil.

Amla oil has obtained a transmission (%) of 32.18%, 24.54%, 22.18%, and 69.87% at the wavelength of 532.3 nm, 590.3 nm, 636.1 nm, and 922.9 nm respectively. Transmission (%) of 48.77%, 75.19%, 68.12%, and 71.79% is obtained at the wavelength of 634.9 nm, 754.1 nm, 924.9 nm, and 933.5 nm respectively corresponding to the red palm oil. It has been observed that in the wavelength range of 920 nm to 935 nm all the oils have obtained a change in the transmission (%).

Figure 3 (b) represents the change in the absorbance behavior of all oil samples responding differently under the same conditions.

Olive oil has obtained an absorbance (Au) of 0.968 Au, 0.092 Au, 0.095 Au, and 0.121 Au at the wavelength of 358.7 nm, 651.7 nm, 900.7 nm, and 920 nm respectively.

Absorbance (Au) of 2.142 Au, 0.194 Au, 0.105 Au, and 0.141 Au is obtained at a wavelength of 466.4 nm, 663.1 nm, 857.1 nm, and 920.8 nm respectively for the mustard oil.

Amla oil has obtained absorbance (Au) of 2.219 Au, 0.491 Au, 0.654 Au, and 0.153 Au at a wavelength of 447.2 nm, 539.2 nm, 642.2 nm, and 925.8 nm respectively.

Absorbance (Au) of 2.647 Au, 0.309 Au, 0.146 Au, and 0.163 Au at a wavelength of 519.6 nm, 639.4 nm, 911.4 nm, and 930.2 nm respectively is obtained corresponding to the red palm oil.

Table 1: Transmission and absorbance of the household oil samples

| S.No | Oil Sample | Wavelength (nm) | Transmission (%) | Wavelength (nm) | Absorbance (AU) | Shift in wavelength (nm) |
|------|------------|----------------|------------------|----------------|-----------------|--------------------------|
| 1    | Olive oil  | 923.2          | 75.66            | 920.0          | 0.121           | 3.2                      |
| 2    | Mustard oil| 924.5          | 71.10            | 923.0          | 0.141           | 1.5                      |
| 3    | Amla oil  | 925.9          | 69.87            | 925.8          | 0.153           | 0.1                      |
| 4    | Redpalm oil| 927.8          | 68.12            | 930.2          | 0.163           | 2.4                      |
A linear relationship between the wavelength (\(nm\)), transmission (\%), and absorbance (\(A_u\)) is essential for device optimization. Table (1) represents the transmission (\%) and absorbance (\(A_u\)) corresponding to the different oil samples in the wavelength range of 920 \(nm\) to 935 \(nm\). The linear fitting of degree (1) and degree (2) between the wavelength and transmission (\%) is presented in Figure 4 (a & b), respectively. Similarly, the linear fitting of degree (1) and degree (2) between the wavelength and absorbance (\(A_u\)) is presented in Figure 4 (c & d), respectively. The goodness of the curve fitting is obtained with a 95\% confidence bound. Conventional fitting parameters like “sum of squared error (SSE),” “\(R - square\),” “Adjusted R-Square,” and “root means square error (RMSE)” are obtained and tabulated in Table (2).

![Figure 4](image.png)
Table 2: Fitting parameters for transmission (%) and absorbance (\(A_u\)) corresponding to the wavelength (920 nm-935 nm)

| S.No | Variables | Developed relationship between Tx. (%) vs. wavelength and Ab. vs. wavelength | The goodness of the fitting parameters (95 % confidence bound) |
|------|-----------|--------------------------------------------------------------------------------|-------------------------------------------------------------|
|      |           | \( f(eq) = l_1(Tx) + l_2 \) \( l_1 = -1.526 \) \( l_2 = 1484 \) | \( \text{RMSE} \) \( \text{Adjusted } R - \text{Square} \) \( R - \text{Square} \) \( SSE \) |
| 1    | Tx. vs. wavelength (Degree 1) | \( f(eq) = l_1(Tx)^2 + l_2(Tx) + l_3 \) \( l_1 = 0.3734 \) \( l_2 = -692.7 \) \( l_3 = 3.213 \times 10^6 \) | 1.417 0.8066 0.8711 4.016 |
| 2    | Tx. vs. wavelength (Degree 2) | \( f(eq) = l_1(Ab)^2 + l_2(Ab) + l_3 \) \( l_1 = 0.004032 \) \( l_2 = -3.584 \) | 0.9392 0.9151 0.9717 0.8822 |
| 3    | Ab. vs. wavelength (Degree 1) | \( f(eq) = l_1(Ab)^2 + l_2(Ab) + l_3 \) \( l_1 = 0.003312 \) \( l_2 = 0.6162 \) \( l_3 = -287.1 \) | 0.00556 0.9053 0.9368 6.18x10^{-5} |
| 4    | Ab. vs. wavelength (Degree 2) | \( f(eq) = l_1(Ab)^2 + l_2(Ab) + l_3 \) \( l_1 = -0.003312 \) \( l_2 = 0.6162 \) \( l_3 = -287.1 \) | 0.000568 0.999 0.9997 3.227x10^{-7} |

**B. Development of empirical model for Transmission and Absorbance**

In this section, empirical modeling is done corresponding to the spectrum plots of the oil samples. The empirical models are presented using 8th order sinusoidal expression, which best fits the oil spectrums, with maximum fitting parameters. The developed model for the transmission and absorbance for the oil samples is presented in Equation (16).

\[
f(wl) = a_1 \sin(b_1 \, wl + c_1) + a_2 \sin(b_2 \, wl + c_2) + a_3 \sin(b_3 \, wl + c_3) + a_4 \sin(b_4 \, wl + c_4) + a_5 \sin(b_5 \, wl + c_5) + a_6 \sin(b_6 \, wl + c_6) + a_7 \sin(b_7 \, wl + c_7) + a_8 \sin(b_8 \, wl + c_8)
\]

(16)

The numerical values of the constant \(a_1 \ldots \ldots a_8, b_1 \ldots \ldots b_8,\) and \(c_1 \ldots \ldots c_8\) are tabulated in Table (3) corresponding to the transmission (%). Figure (5) represents the sinusoidal fitting of 8th order corresponding to transmission (%) for different oil samples.

Table (3): Numerical values of the constant \(a_i, b_i,\) and \(c_i\) for transmission (%) \((1 \leq i \leq 8)\)

| S.No | Oil      | Numerical Constants | Numerical Constants | Numerical Constants | Numerical Constants |
|------|----------|---------------------|---------------------|---------------------|---------------------|
| 1    | Amla Oil | \(a_1 = 68.14\)    | \(a_2 = 41.1\)     | \(a_3 = 14.56\)    | \(a_4 = 5.372\)     |
| 2    |          | \(b_1 = 0.002888\) | \(b_2 = 0.005896\) | \(b_3 = 0.01185\)  | \(b_4 = 0.01762\)   |
| 3    |          | \(c_1 = -0.2949\)  | \(c_2 = 1.723\)    | \(c_3 = -0.9662\)  | \(c_4 = -1.452\)    |
Figure 5 (a-d) represents the fitting response of transmission (%) against wavelength (nm). The appropriate response suggests that a slight similarity is obtained in the spectral response of amla oil and red palm oil. Similarly, olive oil and mustard oil show little similarity in their spectral behavior.
Figure 5: 8th order sinusoidal fitting response corresponding to the transmission (%) from the oil samples (a) Olive oil (b) Mustard oil (c) Amla oil (d) Red palm oil

Table (4) presents the values of the constant $a_i$, $b_i$, and $c_i$ where the range of $1 \leq i \leq 8$. It is corresponding to the absorbance ($Au$).

Table (4): Numerical values of the constant $a_i$, $b_i$, and $c_i$ for absorbance ($Au$)

| S.No | Oil       | Numerical Constants | Numerical Constants | Numerical Constants | Numerical Constants |
|------|-----------|---------------------|---------------------|---------------------|---------------------|
| 1    | Amla Oil  | $a_1$ 0.863         | $a_2$ 0.9099        | $a_3$ 0.2769        | $a_4$ 0.3036        |
| 2    | Amla Oil  | $b_1$ 0.003202      | $b_2$ 0.006192      | $b_3$ 0.01186       | $b_4$ 0.03012       |
| 3    | Amla Oil  | $c_1$ -1.055        | $c_2$ -0.7239       | $c_3$ 3.107         | $c_4$ 2.346         |
| 4    | Amla Oil  | $a_5$ 0.1645        | $a_6$ 0.3474        | $a_7$ 0.2811        | $a_8$ 0.2787        |
| 5    | Redpalm Oil | $b_5$ 0.01851    | $b_6$ 0.0276        | $b_7$ 0.04102       | $b_8$ 0.04159       |
| 6    | Redpalm Oil | $c_5$ 0.3526         | $c_6$ -4.616        | $c_7$ -5.901        | $c_8$ 2.75          |
| 7    | Redpalm Oil | $a_1$ 0.1613         | $a_2$ 0.4638        | $a_3$ 0.3234        | $a_4$ 1.738         |
| 8    | Redpalm Oil | $b_1$ 0.003321      | $b_2$ 0.0122        | $b_3$ 0.01863       | $b_4$ 0.005327      |
| 9    | Redpalm Oil | $c_1$ -1.387        | $c_2$ 2.199         | $c_3$ -1.372        | $c_4$ -0.1587       |
| 10   | Redpalm Oil | $a_5$ 0.2542        | $a_6$ 0.1886        | $a_7$ 0.1199        | $a_8$ 0.8099        |
| 11   | Redpalm Oil | $b_5$ 0.02266       | $b_6$ 0.03222       | $b_7$ 0.0396        | $b_8$ 0.04687       |
| 12   | Redpalm Oil | $c_5$ 3.525         | $c_6$ -2.354        | $c_7$ 0.09908       | $c_8$ -3.931        |
| 13   | Olive Oil  | $a_1$ 0.3032        | $a_2$ 0.2111        | $a_3$ 0.1076        | $a_4$ 0.05381       |
| 14   | Olive Oil  | $b_1$ 0.002584      | $b_2$ 0.005054      | $b_3$ 0.02349       | $b_4$ 0.03112       |
| 15   | Olive Oil  | $c_1$ 0.08799       | $c_2$ 1.028         | $c_3$ 0.2926        | $c_4$ -2.984        |
| 16   | Olive Oil  | $a_5$ 0.1509        | $a_6$ 0.8476        | $a_7$ 0.8426        | $a_8$ 0.1022        |
| 17   | Olive Oil  | $b_5$ 0.01913       | $b_6$ 0.0408        | $b_7$ 0.0408        | $b_8$ 0.01475       |
| 18   | Olive Oil  | $c_5$ 0.9361        | $c_6$ 1.223         | $c_7$ 1.223         | $c_8$ -4.645        |
Figure (6) represents the 8th order sinusoidal fitting corresponding to absorbance ($A_u$) for different oil samples. The absorbance plots of all the oil samples showed slight similarity in their spectrum curves, but the absorbance value differs for all oil samples.

|                | $a_1$  | $a_2$ | $a_3$  | $a_4$  | $b_1$ | $b_2$  | $b_3$  | $b_4$  | $c_1$ | $c_2$  | $c_3$  | $c_4$  | $a_5$ | $a_6$  | $a_7$  | $a_8$  | $b_5$ | $b_6$  | $b_7$  | $b_8$  | $c_5$ | $c_6$  | $c_7$  | $c_8$  |
|----------------|--------|-------|--------|--------|-------|--------|--------|--------|-------|--------|--------|--------|-------|--------|--------|--------|-------|--------|--------|--------|-------|--------|--------|--------|
| Mustard Oil    | 0.7033 | 0.3133| 0.4607 | 0.7046 | 0.001209 | 0.01886 | 0.01245 | 0.005639 |
| Amla Oil       | -0.2069| 0.01575| 2.609  | -0.6599|
| Mustard Oil    | 0.2437 | 0.1732| 0.1146 | 0.07167|
| Olive Oil      | 0.02738| 0.03225| 0.04326| 0.04685|
| Olive Oil      | -4.551 | 0.3896| -6.4   | -0.4682|

Figure 6: 8th order sinusoidal fitting response corresponding to the absorbance ($A_u$) from the oil samples (a) Red palm oil (b) Amla oil (c) Mustard oil (d) Olive oil
Sinusoidal fitting of the $8^{th}$ order is selected in this experiment because this curve fitting is closest to the ideal with good fitting values. The fitness parameters obtained for the transmission (%) and absorbance ($Au$) are tabulated in Table (5). From the fitting parameters, it is observed that the value of R-square is close to unity for both transmission (%) and absorbance ($Au$). $SSE$ and $RMSE$ have higher values for transmission (%) than absorbance ($Au$). The obtained value of the fitting parameters is obtained assuming the wavelength in (nm) scale.

Table 5: Fitting parameters corresponding to $8^{th}$ order sinusoidal fitting

| S.No | Spectrum behavior | Oil Samples | $SSE$       | $R - Square$ | Adjusted $R - Square$ | $RMSE$ |
|------|-------------------|-------------|-------------|--------------|------------------------|--------|
| 1    | Transmission (%)  | Olive oil   | $3.579 \times 10^4$ | 0.9705       | 0.9703                 | 3.141  |
| 2    |                   | Mustard oil | $3.738 \times 10^4$ | 0.9861       | 0.9861                 | 3.209  |
| 3    |                   | Amla oil    | $2.943 \times 10^4$ | 0.9877       | 0.9877                 | 2.848  |
| 4    |                   | Red palm oil| $4.605 \times 10^4$ | 0.9834       | 0.9833                 | 3.562  |
| 5    | Absorbance (Au)   | Red palm oil| 49.83       | 0.9777       | 0.9776                 | 0.1172 |
| 6    |                   | Amla oil    | 31.45       | 0.9764       | 0.9761                 | 0.1084 |
| 7    |                   | Mustard oil | 29.00       | 0.9756       | 0.9754                 | 0.0893 |
| 8    |                   | Olive oil   | 7.22        | 0.9429       | 0.9425                 | 0.04463|

Thus the generalized form for the developed model is presented in Equation (17).

$$f(wl) = \sum_{i=1}^{8} a_i \sin(b_iwl + c_i)$$

(17)

Where $200 \text{ nm} \leq wl \leq 1200 \text{ nm}$ respectively.

4. Conclusion

A low-cost $UV – Vis – NIR$ sensing setup (LCSS) is developed and presented in this work to analyze transmission (%) and absorption ($Au$) from household oils samples. The sensing capability of the developed setup is investigated using four different oil samples. These oil samples consist of olive oil, mustard oil, amla oil, and red palm oil. The transmission (%) obtained for olive oil, mustard oil, amla oil, and red palm oil is 75.66%, 71.10%, 69.87%, and 68.12% at 923.2 nm, 924.5 nm, 925.9 nm, and 927.8 nm respectively. Similarly, the absorbance ($Au$) for olive oil, mustard oil, amla oil, and red palm oil is 0.121 Au, 0.141 Au, 0.153 Au, and 0.163 Au at 920.0 nm, 923.0 nm, 925.8 nm, and 930.2 nm respectively. A linear relationship in the wavelength range of 920 nm to 935 nm between transmission (%) and wavelength produce $R^2 = 0.9717$ corresponding to a degree (2). Similarly, the linear
relation between absorbance \((A_u)\) and wavelength produce \(R^2 = 0.9997\) corresponding to a degree (2). Finally, an 8th order empirical sinusoidal model is developed for transmission (\(\%\)) and absorbance (\(A_u\)) corresponding to the olive oil, mustard oil, amla oil, and red palm oil. The maximum value of \(R^2\) corresponding to the transmission (\(\%\)) for the developed empirical model is obtained for Amla oil. Similarly, the full value of the absorbance (\(A_u\)) from the developed empirical model is obtained for red palm oil, which indicates a great response towards the empirical sinusoidal model. Thus the developed LCSS have tremendous potential to analyze various liquids, chemicals, analytes, and oils samples in the \(UV − Vis − NIR\) spectrum range.

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