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 absorbance (*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 spectrometers 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 $10\text{ nm} – 400\text{ nm}$ [13]. This range can be further divided into three different bands, i.e., *UVA* ($315\text{ nm} – 400\text{ nm}$), *UVB* ($280\text{ nm} – 315\text{ nm}$) and *UVC* ($100\text{ nm} – 280\text{ nm}$) [14]. The range of the visible spectrum is $400\text{ nm} – 700\text{ nm}$ 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 $200\text{ nm} – 1200\text{ nm}$, 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 spectrosopes 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_{in}) is entering the sample and the light beam of intensity (I_{out}) 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).

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

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

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

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

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

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

$$\log\left(\frac{I_{in}}{I_{out}}\right) = -\alpha L \quad (7)$$

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

$$I_{in} = I_{out} e^{-\alpha L} \quad (9)$$

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].

$$Transmission = (I_{in}/I_{out}) [Unitless] \quad (10)$$

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

$$Transmission (\%) = (I_{in}/I_{out}) \times 100 \quad (11)$$

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].

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

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).

$$Transmission (\%) = (I_{in} - I_{Dark} / I_{Out} - I_{Dark}) \quad (14)$$

$$Absorbance (Ab) = -\log_{10} \frac{I_{in} - I_{Dark}}{I_{Out} - I_{Dark}} \quad (15)$$

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

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 $\times$ 12.5 mm $\times$ 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).

Figure 2: (a) LCSS developed to analyze common household oils (b) (i) Olive oil (ii) Mustard oil (iii) Amla oil (iv) Red palm oil; Quartz cuvettes with oil samples (c) Amla oil (d) Mustard oil (e) Olive oil (f) Red palm oil (g) 2D cross-section of the M93L01 optical fiber

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 (Au) is essential for device optimization. Table (1) represents the transmission ($\%$) and absorbance (Au) 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 (Au) 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: Polynomial fitting between the transmission ($\%$) vs. wavelength (a) degree (1) (b) degree (2); Polynomial fitting between the absorbance (AU) vs. wavelength (c) degree (1) (d) degree (2)

Table 2: Fitting parameters for transmission (%) and absorbance (Au) 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)			
			$RMSE$	Adjusted R – Square	R – Square	SSE
1	Tx . vs. wavelength (Degree 1)	$f(eq) = l_1(Tx) + l_2$ $l_1 = -1.526$ $l_2 = 1484$	1.417	0.8066	0.8711	4.016
2	Tx . vs. wavelength (Degree 2)	$f(eq) = l_1(Tx)^2 + l_2(Tx) + l_3$ $l_1 = 0.3734$ $l_2 = -692.7$ $l_3 = 3.213 \times 10^5$	0.9392	0.9151	0.9717	0.8822
3	Ab . vs. wavelength (Degree 1)	$f(eq) = l_1(Ab) + l_2$ $l_1 = 0.004032$ $l_2 = -3.584$	0.00556	0.9053	0.9368	6.18×10^{-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	3.227×10^{-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).

$$f(wl) = a_1 \sin(b_1 wl + c_1) + a_2 \sin(b_2 wl + c_2) + a_3 \sin(b_3 wl + c_3) + a_4 \sin(b_4 wl + c_4) + a_5 \sin(b_5 wl + c_5) + a_6 \sin(b_6 wl + c_6) + a_7 \sin(b_7 wl + c_7) + a_8 \sin(b_8 wl + c_8) \quad (16)$$

The numerical values of the constant $a_1 \dots a_8$, $b_1 \dots b_8$, and $c_1 \dots c_8$ 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

4		a_5	9.358	a_6	4.894	a_7	1.933	a_8	3.778
5		b_5	0.0262	b_6	0.04302	b_7	0.02984	b_8	0.03592
6		c_5	0.5836	c_6	3.005	c_7	-0.6262	c_8	0.4505
7	Redpalm Oil	a_1	75.54	a_2	34.41	a_3	26.95	a_4	3.933
8		b_1	0.002512	b_2	0.01011	b_3	0.005222	b_4	0.02323
9		c_1	-0.5199	c_2	-0.04321	c_3	1.145	c_4	4.316
10		a_5	8.706	a_6	4.176	a_7	3.212	a_8	3.061
11		b_5	0.01618	b_6	0.03504	b_7	0.05278	b_8	0.04345
12		c_5	-1.935	c_6	-1.311	c_7	-5.186	c_8	-4.835
13	Olive Oil	a_1	113.8	a_2	38.67	a_3	18.43	a_4	17.61
14		b_1	0.003082	b_2	0.00614	b_3	0.01307	b_4	0.01836
15		c_1	-0.6446	c_2	0.5957	c_3	-0.8439	c_4	-1.831
16		a_5	10.45	a_6	4.882	a_7	22.68	a_8	22.14
17		b_5	0.02361	b_6	0.03154	b_7	0.04053	b_8	0.04118
18		c_5	3.315	c_6	0.07165	c_7	-4.509	c_8	4.374
19	Mustard Oil	a_1	446.1	a_2	50.28	a_3	327.9	a_4	11.02
20		b_1	0.001956	b_2	0.008675	b_3	0.003779	b_4	0.02153
21		c_1	1.496	c_2	2.568	c_3	3.406	c_4	-5.076
22		a_5	8.37	a_6	5.144	a_7	6.45	a_8	2.248
23		b_5	0.02721	b_6	0.03989	b_7	0.0438	b_8	0.07088
24		c_5	5.712	c_6	3.382	c_7	2.959	c_8	-4.633

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		b_1	0.003202	b_2	0.006192	b_3	0.01186	b_4	0.03012
3		c_1	-1.055	c_2	-0.7239	c_3	3.107	c_4	2.346
4		a_5	0.1645	a_6	0.3474	a_7	0.2811	a_8	0.2787
5		b_5	0.01851	b_6	0.0276	b_7	0.04102	b_8	0.04159
6		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		b_1	0.003321	b_2	0.0122	b_3	0.01863	b_4	0.005327
9		c_1	-1.387	c_2	2.199	c_3	-1.372	c_4	-0.1587
10		a_5	0.2542	a_6	0.1886	a_7	0.1199	a_8	0.8099
11		b_5	0.02266	b_6	0.03222	b_7	0.0396	b_8	0.04687
12		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		b_1	0.002584	b_2	0.005054	b_3	0.02349	b_4	0.03112
15		c_1	0.08799	c_2	1.028	c_3	0.2926	c_4	-2.984
16		a_5	0.1509	a_6	0.8476	a_7	0.8426	a_8	0.1022
17		b_5	0.01913	b_6	0.0408	b_7	0.0408	b_8	0.01475
18		c_5	0.9361	c_6	1.223	c_7	1.223	c_8	-4.645

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

Figure (6) represents the 8th order sinusoidal fitting corresponding to absorbance (Au) 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.

Figure 6: 8th order sinusoidal fitting response corresponding to the absorbance (Au) from the oil samples (a) Red palm oil (b) Amla oil (c) Mustard oil (d) Olive oil

Sinusoidal fitting of the 8th 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 8th order sinusoidal fitting

S.No	Spectrum behavior	Oil Samples	<i>SSE</i>	<i>R – Square</i>	Adjusted <i>R – Square</i>	<i>RMSE</i>
1	Transmission (%)	Olive oil	3.579×10^4	0.9705	0.9703	3.141
2		Mustard oil	3.738×10^4	0.9861	0.9861	3.209
3		Amla oil	2.943×10^4	0.9877	0.9877	2.848
4		Red palm oil	4.605×10^4	0.9834	0.9833	3.562
5	Absorbance (<i>Au</i>)	Redpalm 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).

$$f(wl) = \sum_{i=1}^8 a_i \sin(b_i wl + c_i) \quad (17)$$

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 (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. 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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