

Contactless Optical Liquid Identifier

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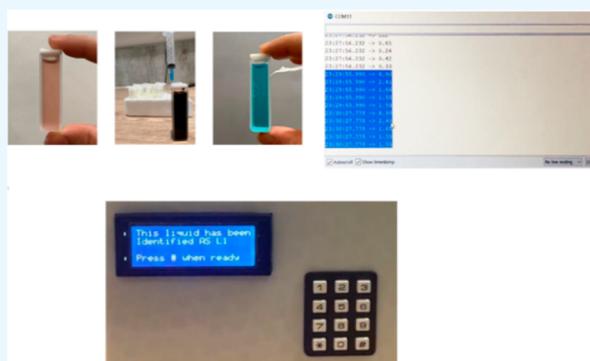
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ABSTRACT: This paper presents the development of a portable device that can be used for liquid identification using the concept of Beer–Lambert law. The final device can recognize up to 30 different materials in their liquid state and provides some other useful features that can enhance its operation. The user can set a group of 30 liquids according to specific needs and applications. The device can provide the user with some specific settings to start the measurements. The volume of a fluid is identified by a 4 mL sample inserted in the cuvette, then the user can start measuring the concentration of some common solvents like methanol, ethanol, etc. by passing a light of different wavelengths through the sample. The amount of the transferred light is measured using photodetectors and the readings depend on the amount of absorption. The amount of absorption depends on the sample types, colors, contents, and concentrations, so it is used as the main indicator to identify a specific sample.



1. INTRODUCTION

The devices used nowadays for fluid detection and identification are bulky and expensive ranging from 40,000 \$ to 60,000\$.^{1,2} Different techniques have to be developed to replace the existing devices, the new techniques should be more affordable to use them in a wider range. Fluid identification systems are necessary in many sectors. They are used in the airport security to check for any explosive liquids or narcotics materials before being passed through country borders.^{3–6} They are also used in drugs and pharmaceutical detection in medicine production factories to check the products before they are sent out to the market.⁵ Moreover, they are used in laboratories for educational means and for different research experiments.^{1–6} The first device invented for liquid identification was an UV spectrophotometer in 1941 by Beckman and his colleagues at National Technologies Laboratories.^{4,5} The idea came as a result of Arnold J. Beckman's interest in testing complex biological samples. The amplifier in a Beckman pH meter commercial device was well suited to be used with the phototubes. The spectrophotometry development began in the company in the early 1940s, the yield product had multiple versions and improvements, it started from type A to type D.^{4,5} Type A was designed by combining a glass prism, a vacuum tube, and the amplifier from a Beckman pH meter; however, its performance was not quite good so it was immediately modified to type B. In type B, the glass prism was replaced by a Quartz one to improve the UV wavelength ranges used. The device development was continued until a famous DU-spectrophotometer was achieved to provide a wide range of UV beams by

including a hydrogen lamp and an improved monochromator.^{4,5} The scientists used a spectrophotometer to examine and identify a given substance based on its absorption spectrum.^{1,2,4–7} Several techniques were developed to serve the same purpose of analysis,^{3,8–20} each technique uses a different macromolecular reaction to detect the sample.

One of the important techniques used to identify a sample is fluorescence spectroscopy. In this technique, when a source of light is used to activate the electrons in molecules of a certain compound, the electrons of the specimen molecules absorb sufficient energy to move to a higher energy state after a period of time. Then, the electron tends to lose this gained energy and recombine when it moves back to the lower state of energy leading to an emission of energy in a state of a photon; the emitted photon energy reflects the properties of a specific specimen, which can be derived by special calculations.^{8,9}

UV–vis spectrophotometers measure the absorbance or transmittance of light passing through a medium as a function of the wavelength. The calculation depends on the quantum number that the material absorbs throughout the illumination process. UV–vis spectrophotometers direct a light source through a sample and a detector on the opposite side records

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the transmitted light, the transmittance represents how much light is absorbed at each wavelength.¹⁶

Fourier-transform infrared spectroscopy (FTIR) offers precise analysis for organic and inorganic samples by an infrared absorption spectrum. In this process, a light beam containing different frequencies is emitted on the specimen to measure how much of light is absorbed by the sample.¹⁹ Next, the beam is modified to contain different combinations of frequencies to achieve a second data point. This process is rapidly repeated many times over a short time span. The generated absorption spectrum produces a distinctive fingerprint depending on the molecular composition of the specimen that can be used to scan samples for identification and analysis. This method is complex and needs experts to use it because the whole process depends on an advanced computer processing software to turn the raw data, i.e., the light absorption for each mirror position into the desired result, i.e., the light absorption for each wavelength.⁷

Most of the recent work focus on reducing the size and cost of spectrophotometers. Tymecki et al.¹⁵ proposed an alternative approach to paired emitter detector diode PEDD-based photometry that enables optical measurements using only extremely low-cost LEDs and potentiometric pH-meters that are available in almost all analytical laboratories. The analyte concentration is measured by providing a stable voltage signal that is directly proportional to the absorbance of the sample.

Wide-band wireless signals have been used in several papers to classify liquids using simple and cheap systems.^{21–25} The liquid can be identified when estimating its permittivity by noninvasively shining the wireless signals through it. Wang et al.²⁴ proposed a system that is capable to identify 10 liquids using RFID readers and tags. In a more improved work, Dhekne et al.²⁵ have developed a wireless liquid identifier that uses ultra-wideband wireless signals with a 4 GHz center frequency and a 1 GHz bandwidth to identify 33 different liquids. When a wireless signal passes through a liquid, it experiences distinct slow-down and attenuation manifesting in the phase, strength, and propagation delay of the outgoing signal. Therefore, because each liquid has a different refractive index and loss factor, each liquid will be identified by a different permittivity spectrum that can be considered as its signature.

Zhang et al.²⁶ have designed A portable water analyzer based on a spectrophotometer. The design consists of a long-life light source that contains 6 LEDs and the light signal is transformed into an electric signal using a photodiode sensor. The LEDs on/off is analyzed using a microcontroller, and an LCD is used to display the results. The peak wavelengths selected for water quality monitoring include 420, 455, 515, 560, 605, and 630 nm, that can cover multiple parameters that might exist in water like ammonia nitrogen, nitrite nitrogen, hexavalent chromium, and arsenate up to 45 types. The optical absorbance of a sample is measured to determine the water content. The result presented in their work show high repeatability and good linearity which make the system suitable for laboratory and in situ river water tests.

Bano et al.¹² have implemented a cost effective portable spectrophotometer that contains a 60 watt bulb as a light source and a compact disc (CD) media as a diffraction grid and. A monochromatic light is obtained using a moving slit along with a stepper motor. The intensity of light is determined using a photocell with spectral sensitivity in the

visible region and an amplifier with a very high gain. The proposed instrument control, acquisition, and the treatment of data is done using an electronic circuit based on an AVR microcontroller ATmega32. The device provided good results at all visible wavelengths of light, and it is successfully applied to determine the absorbance and transmittance of KMnO_4 and its unknown concentration using the calibration curve.

Recently, Han et al.²⁷ developed a miniaturized portable/online UVC-LED spectrophotometer for fast detection of nitrate nitrogen and dissolved organic matter. They have used 235 and 275 nm light-emitting diodes (LEDs) as the light sources and GaN-based photodiodes as UV detectors. They achieved good linearity for NO_3^- -N concentrations in the range of 0–15 mg/L ($R_2 > 0.99$), while at higher NO_3^- -N concentrations, a loss of sensitivity was observed.

More recently, Ohol and Vasuki²⁸ presented the development of a system that contains a minifluidic active mixer for different properties of liquid mixing and uses a UV–visible spectrophotometer to measure the unmixed and mixed solution's absorbance values at the maximum absorptivity λ_{max} . The mixer consists of the SP-5H piezoelectric patch pasted on an aluminum beam. The patch and the aluminum beam act as a piezoelectrically vibrating beam. The patch starts vibrating when it is excited by a suitable voltage, and the generated vibration energy moves from the beam to the test liquid inside the tank. As a result, a robust circulation of liquid will happen in all directions. Aqueous alcohol and aqueous alcohol viscous solutions were mixed using the proposed system, the proposed technique also used to mix solutions of different dye concentrations in the solvent, deionized (DI) water, and ethanol. The absorbance of unmixed 5 mg L⁻¹ aqueous methyl red and 10 mg L⁻¹ alcohol-based bromothymol blue solutions (0.065 and 0.598 at 410 and 431 nm, respectively) were measured using a spectrophotometer. The absorbance of the mixed solution was 0.029 and 0.032 at 410 and 431 nm, respectively.

Furthermore, Xing et al.²⁹ have created a multi-channel colorimetric sensor tailored for cellphones capable of concurrently quantifying numerous environmental pollutants with remarkable precision and steadiness. They implemented a diffraction grating to divide six white beams that traverse multiple colored samples. This sensor proves versatile in gauging a diverse array of environmental contaminants, utilizing the colorimetry assay spanning the 400–700 nm spectrum. Their sensor effectively identified turbidity, orthophosphate, ammonia nitrogen, and three heavy metals in a simultaneous manner, achieving impressive sensitivity levels.

In this paper, we present the development of a portable affordable device that uses the concept of Beer–Lambert law for liquid identification. In our approach, the measurement system employs multiple wavelengths, eliminating the necessity for a diffraction grid or monochromator. We offer a fully enclosed device, equipped with a sample cuvette inlet that can be conveniently sealed using a sliding lid, enhancing its practicality. The arrangement of the cuvette holder and the utilization of a quartz cuvette were instrumental in achieving light emission onto the sample, obviating the requirement for external optical fibers or lenses. The device introduced in this work is cost-effective, precise, user-friendly, and features straightforward configuration that does not necessitate specialized expertise for operation.

The main parts of the system include: a transmitting side board that has light sources to emit lights of different wavelengths, a receiver side board that includes photodetectors to measure the transmitted signal, a cuvette to hold a sample, a microcontroller (Arduino Mega 2560), LCD screen, and a keypad for the user interface. The main operation principle of the system designed in this work is similar to the concept used by Flaschka et al.¹¹ and Bano et al.¹² The final device allows the user to set a group of 30 liquids according to specific needs and applications. The device can provide the user with some specific settings to start the measurements. The volume of a fluid is identified by a 4 mL sample inserted in the cuvette, then the user can start measuring the concentration of some common solvents like methanol, ethanol, etc. by passing a light of different wavelengths through the sample. The amount of the transferred light is measured using photodetectors and the readings depend on the amount of absorption. The amount of absorption depends on the sample types, colors, contents, and concentrations, so it is used as the main indicator to identify a specific sample.

2. MATERIALS AND METHODS

In this work, we have used a principle that is similar to UV–visible spectroscopy^{4,5,16} but with a cheaper and more suitable setup that can provide a contactless identification of a specific sample. The proposed system is mainly designed for liquid analysis and relies on the Beer–Lambert law.^{8,10} The optical based electronic device was built using a set of SMD light emitting diodes (LEDs) that operates on different wavelength levels without the need to add a diffraction grid or monochromator.^{11,12,26,27} The operation principle of the system depends on sending a radiation from a light emitting source, then the emitted photons penetrates through the sample, part of them is going to be absorbed, and the rest is going to be passed through to the other side of the sample container. The amount of light passed through the sample to the other side is measured by specific photodetectors and the readings depend on the amount of absorption. The amount of absorption depends on the sample types, colors, contents, and concentrations, so it is used as the main indicator to identify a specific sample. Our goal is mainly to design a lightweight portable device that has the capability to analyze liquids in the matter of seconds and even determine some common solvents concentration using optical radiation. Moreover, because every specific material has its own unique response to each wavelength, a signature is created for this material distinguishing it from any other substance.

2.1. Optical System. The light emission utilizes five different SMD LEDs that function to emit light to the specimen. Part of the light is absorbed by the specimen, and another part is transmitted to reach the other side of the holder. The transmitted light is collected and measured by specific phototransistors. Each of the used phototransistors matches the exact wavelength of the emitted light for the best response and have a peak sensitivity to match the wavelength of the emitted light. Figure 1 shows the optical system of the device including the transmitter and the receiver PCBs and the cuvette in the middle.

The main mechanism of the liquid identification developed in this work depends on the Beer–Lambert law.^{8,10} As the light beam heads toward the specimen, I_o penetrates through the sample, then transmitted to the other side I_t , and the absorbed intensity of light is expressed as

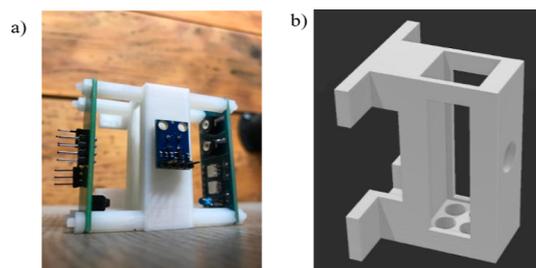


Figure 1. (a) Optical system of the device. (b) Cuvette holder 3D design.

$$I_{\text{abs}} = I_o - I_t \quad (1)$$

where: I_o : the intensity of the incident light. I_t : the intensity of the transmitted light. I_{abs} : the intensity of the light absorbed by the specimen.

The light absorbance (A), also known as the optical density (OD), is defined as the quantity of light absorbed by a solution is as follows

$$A = \log(I_o/I_t) \quad (2)$$

The Beer–Lambert law is a linear relationship between the absorbance of the solution, the concentration, molar absorption coefficient, and the optical path length of a solution

$$A = \epsilon CL \quad (3)$$

where: A : absorbance. ϵ : molar absorption coefficient $\text{M}^{-1} \text{cm}^{-1}$. C : molar concentration in M . L : optical path length in cm .

2.2. Cuvette Holder. The model of the device holder was designed using a Fusion 360 (Figure 1b). The holder was printed using a 3D printer to fit the exact same sizes of the components. Holding the transmitter and the receiver boards through two facing vents that wrap both of cuvette clear sides, for the proper emission of the beam lights. In addition to the temperature sensor (GY-906) vent that is used to measure the solution temperature to ensure collecting all readings at the same temperature.

The design's optical path length is fixed at 10 mm relative to the special container with fixed dimensions (45 mm \times 12.5 mm \times 12.5 mm), this container is used to inject the sample and is typically made of quartz or plastic, and it is polished to minimize the reflection of light. This special container is a Vernier Quartz Cuvette number 470219-264, a U-shaped cuvette with 2 clear sides for maximum light transmittance with a path length of 10 mm. Because the system design utilizes wavelengths outside the visible region, quartz cuvettes are specifically used for measuring suitable and accurate UV beams, while the plastic cuvettes are typically used for the visible light path range (380–700 nm). Quartz cuvettes provide more durability than plastic or glass, and their walls are more resistant to scratching.³⁰ Quartz excels at transmitting UV and IR light, with a minimal reflection of light (less than 10%) and can be used for wavelengths ranging from 170 to 2500 nm. Figure 2 shows the quartz cuvette used in this project.

2.3. Transmitting Side Board. A variety of different wavelengths beams emitted from SMD light-emitting diodes integrated on a single 50 \times 20 mm printed circuit board designed to fit all the necessary components, including the LEDs (OEM P0162 1W UV SMD—Ultraviolet LED, YETDA 5050BRG4 SMD RGB LED, and TCRT5000 IR LED) and the



Figure 2. Quartz cuvette used.

current limiting resistors to protect the LEDs from any overflow and prevent the system from any damage. Each LED has its own controlling pin, which is connected directly to a microcontroller to control its status (ON or OFF), wavelength, and brightness. Although the board itself is 50×20 mm, all the LEDs are placed in a 40×10 mm rectangle located in the middle of the board, which represents the dimensions of the clear side of the quartz cuvette. The design of the printed circuit board (PCB) (Figure 3b) was done using Altium software (Figure 3a).

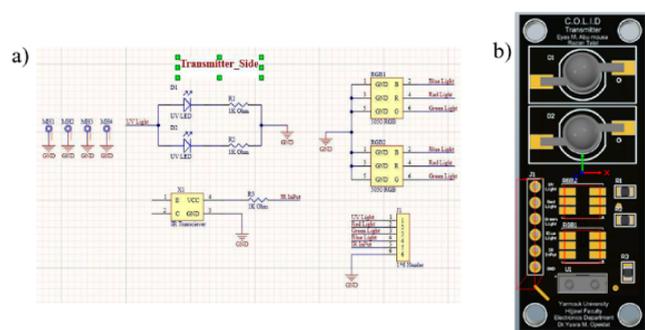


Figure 3. (a) Schematic design of the transmitter side board. (b) PCB layout of the transmitter side board.

2.4. Receiver Side Board. Due to the wide variation in the light wavelengths emitted from the transmitting side and to achieve the optimal accuracy of the light transmission measurements, multiple photosensors with different peak wavelengths, sensitivities, bandwidths, and specifications are used. (TEMT6000 visible light sensor, VEML6075 ultraviolet light sensor, and TCRT5000 IR sensor).

The board also contains a capacitor connected to the UV-sensor to eliminate the noise of the supplied power, and the I2C pull up resistors R_3 and R_4 . See Figure 4.

The transmitting board and the receiver board are designed to fit all the photosensors and other necessary components in a 40×10 mm printed circuit board.

2.5. Display Method. An interacting display (an LCD of 20×4) was used to view the results and track the insertion process to specify the liquids that needs to be identified. A 4×3 Keypad was used and settled on the front side of the 3D-printed package.

2.6. Final Design. In designing our final device, we have chosen a configuration that helps us to measure a correct absorbance, which mainly depends on the ratio between the intensity of the incident and transmitted lights based on the Beer–Lambert law, as described in Section 2.1. The final device was made in such a way that the cuvette holder is placed

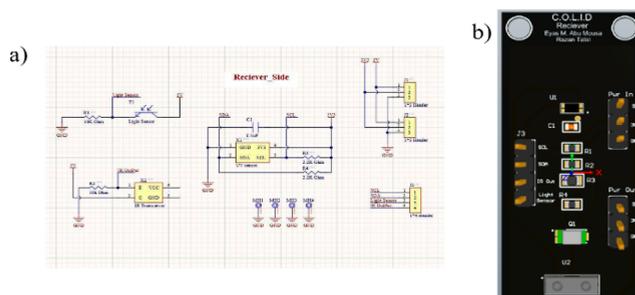


Figure 4. (a) Schematic design of the receiver side board. (b) PCB layout of the receiver side board.

at the middle between the transmitter and receiver side boards. The transmitter board is connected at one end of the holder, while the receiver board is connected at the other end, and the cuvette inlet is at the middle between them. This configuration was chosen to ensure the maximum light penetration through the sample and reduce the amount of loss that might be caused due to scattering in the surrounding area around the sample. The system package was designed to include all parts of the device inside it, this helps in preventing the leakage of light and avoiding any external noise effect on the system output. The system body was shielded with a non-transparent black tape to avoid any penetration of the room light to the optical system. All the device components were controlled and connected using a microcontroller (Arduino Mega 2560) and programmed in the C language through IDE software. The system is powered through a set of three 3.7 V batteries that can be recharged through a micro USB cable, the user will be able to interact with the system using an input and output element, the keypad, and the LCD display. The final prototype of the proposed system is shown in Figure 5.

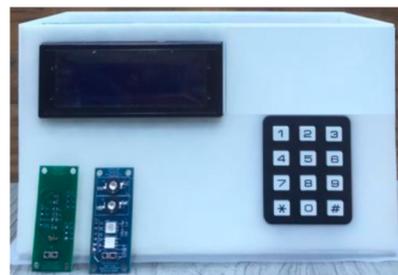


Figure 5. Final prototype of the proposed system.

A new version of the device was made to participate in SOFEX Exhibition, city of Aqaba in Jordan (Figure 6)

2.7. Sample Preparation and Data Collection. Several samples with the specifications shown in Table 1 were tested using the device designed in this work. Before each measurement, the cuvette is filled with 4 mL of a specific sample and inserted inside the cuvette holder, the top side of the device is closed using a sliding lid, and then the user can interact with the system through the keypad and the LCD. Once the user turns on the device, a message will be displayed on the LCD to ask the user to start. The device operates by allowing the user to add the list of liquids he wants to identify based on the application of interest (i.e., food, industry, pharmaceutical and so on). A sample is inserted in the cuvette to allow the system to recognize it and store its corresponding values with its particular nickname so it can be recognized later



Figure 6. Final version of the device.

on. To ensure good selectivity and repeatability, the measurement for each sample was repeated three times and in every test, the device was able to recognize the sample.

Specific samples can be added to the list and stored in the memory of the device. Once the device is turned on, the LCD will display a message to ask the user to start measurement by pressing the hash button #. If he pressed 0 that means he wants to do calibration based on an already stored list of liquids. If he pressed 1 that means he wants to enter a new sample to the list and give it a label to distinguish it from other samples. Finally, if he pressed 2 that means he wants to identify a sample based on a stored list of samples.

The raw data from photosensors are received through the analogue pins and processed to extract the absorption of the specimen that is used as a fingerprint or signature to identify the material inserted. The measured data is controlled using an Arduino Mega 2560 programmed in the C language through IDE software. The code that we have written to program our device, as well as a short video to show the device running are included in the following link: https://yarmoukuniversity2014-my.sharepoint.com/:f/g/personal/yusra_obeidat_yu_edu_

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3. RESULTS AND DISCUSSION

The device designed in this work operates by allowing the user to add the list of liquids that need to be identified according to a range of usage (food industry, pharmaceutical purposes, industrial aspects, quality insurance, and security purposes, etc.). A sample of a fluid is inserted in the container to allow the system to recognize it and store its corresponding values with its particular nickname so it can be recognized later on.

The proposed device uses the transmittance and the absorption values of each specimen to determine its fingerprint. The experiment was conducted on 8 liquids, Table 2 shows every liquid with its absorbance at different wavelengths in 3 runs for each liquid to ensure repeatability.

The results have shown the device capability to identify different liquids and distinguish between them using their absorption signature through a 4 mL sample without any contact with the sample.

The difference between water and alcohol was distinguishable but not in the margin of error used in the device. Therefore, it is necessary to avoid any effect of noise in the comparison process, this was done using two samples from the same liquid, and the measured results have shown the same readings with less than 5% difference between all the values. As a result, keeping the 5% margin of error is leading to a misidentification between water and alcohol in the device.

More experiments were done to show the differences in light absorption between Coca Cola and Pepsi at different wavelengths, as shown in Table 3.

Moreover, we have tested pomegranate at different concentrations and found that the light absorbance increases with the increase in concentration, as shown in Figure 7.

The device designed in this work can be used for different applications, the user can set a group of 30 liquids according to specific needs and applications. This device is simple, portable, and easy to use as it does not need technical experience to apply it for liquid identification. Also, this device is affordable with a cost of only about 100\$, which makes it much cheaper than the commercial fluid detection systems.^{1,2}

Table 1. Different Samples with Different Specifications

sample name	type	color	concentration	preparation
Coca cola	commercial	brown	3.69 ppm	commercial bottles
Pepsi	commercial	brown	6.31 ppm	commercial bottles
raspberry juice	vimto brand	pink	undiluted	commercial bottle
water	distilled	no color	99.9% pure	commercial bottle
ethanol	medical ethyl alcohol	no color	76%	commercial bottle
milk	nadec brand	white	full fat milk, undiluted	commercial bottle
pomegranate molasses ^a	very thick texture	very dark brown	100%	commercial
pomegranate molasses ^a	thick texture	dark brown	75%	dilution: by mixing 3 mL of 100% pomegranate with 1 mL of distilled water
pomegranate molasses ^a	almost thick texture	brown	50%	dilution: by mixing 2 mL of 100% pomegranate with 2 mL of distilled water
pomegranate molasses ^a	light texture	light brown	25%	dilution: by mixing 1 mL of 100% pomegranate with 3 mL of distilled water

^aWe have used a commercial pomegranate molasses and we have a permission to use it and dilute it from the Scientific Research deanship at Yarmouk University.

Table 2. Different Liquids with Their Average Absorbance Values at Different Wavelengths

liquid type		absorbance at 910 nm (AU)	absorbance at 700 nm (AU)	absorbance at 550 nm (AU)	absorbance at 450 nm (AU)	absorbance at 380 nm (AU)
milk	1st run	0.02	1.75	1.98	2.34	1.60
	2nd run	0.02	1.74	1.98	2.35	1.60
	3rd run	0.02	1.75	1.98	2.35	1.60
	average \pm stdv ^a	0.02	1.747 \pm 0.0047	1.98	2.347 \pm 0.0047	1.6
raspberry juice	1st run	0.01	0.0012	1.08	0.63	0.12
	2nd run	0.01	0.0013	1.07	0.63	0.11
	3rd run	0.01	0.0012	1.07	0.64	0.12
	average \pm stdv	0.01	0.00123 \pm 0.0047	1.073 \pm 0.0047	0.633 \pm 0.0047	0.117 \pm 0.0047
water	1st run	0.01	0.12	0.12	0.06	0.01
	2nd run	0.01	0.12	0.12	0.06	0.01
	3rd run	0.01	0.12	0.12	0.06	0.01
	average \pm stdv	0.01	0.12	0.12	0.06	0.01
alcohol	1st run	0.01	0.14	0.13	0.06	0.0
	2nd run	0.01	0.14	0.13	0.06	0.0
	3rd run	0.009	0.14	0.13	0.07	0.0
	average \pm stdv	0.0097 \pm 0.0047	0.14	0.13	0.063 \pm 0.0047	0
pomegranate molasses	1st run	7.21	5.21	5.75	5.82	4.98
	2nd run	7.22	5.21	5.75	5.81	4.98
	3rd run	7.21	5.21	5.75	5.82	5.01
	average	7.213 \pm 0.0047	5.21	5.75	5.817 \pm 0.0047	4.99 \pm 0.014
50% pomegranate molasses	1st run	5.02	3.18	3.65	3.85	3.04
	2nd run	5.023	3.21	3.65	3.9	3.04
	3rd run	5.02	3.21	3.59	3.90	3.07
	average \pm stdv	5.021 \pm 0.0014	3.2 \pm 0.014	3.63 \pm 0.029	3.88 \pm 0.02	3.05 \pm 0.014
75% pomegranate molasses	1st run	6.06	4.11	4.45	4.64	3.88
	2nd run	6.06	4.11	4.45	4.64	3.83
	3rd run	6.06	4.11	4.45	4.64	3.88
	average \pm stdv	6.06	4.11	4.45	4.64	3.863 \pm 0.023
25% pomegranate molasses	1st run	2.47	1.55	1.82	1.86	1.64
	2nd run	2.47	1.55	1.82	1.88	1.64
	3rd run	2.46	1.54	1.82	1.86	1.64
	average \pm stdv	2.467 \pm 0.0047	1.547 \pm 0.0047	1.82	1.867 \pm 0.0094	1.64

^astdv: is the standard deviation error between the three readings.

Table 3. COLID Results of Coca Cola and Pepsi Specimens

liquid type		absorbance at 910 nm (AU)	absorbance at 700 nm (AU)	absorbance at 550 nm (AU)	absorbance at 450 nm (AU)	absorbance at 380 nm (AU)
Coca cola	1st run	0.31	0.67	1.80	2.92	0.94
	2nd run	0.31	0.66	1.80	2.92	0.94
	3rd run	0.31	0.67	1.88	2.93	0.99
	average \pm stdv ^a	0.31	0.667 \pm 0.0047	1.8	2.923 \pm 0.0047	0.957 \pm 0.024
Pepsi	1st run	0.33	0.41	1.23	2.23	0.63
	2nd run	0.32	0.41	1.23	2.28	0.63
	3rd run	0.33	0.41	1.23	2.23	0.63
	Average \pm stdv	0.327 \pm 0.0047	0.41	1.23	2.247 \pm 0.024	0.63

^astdv: is the standard deviation error between the three readings.

In terms of configuration, the measurement system in our work uses several wavelengths without the need to use a diffraction grid or monochromator. We provide a complete device that is shielded and has an inlet for the sample cuvette that can be closed using a sliding lid, which make it more practical. Although the authors in ref 26 have designed a system with several LEDs to analyze water quality based on spectrophotometry, the configuration of their system includes a plastic optical fiber (POF) and a lens to make the divergent

light to parallel light. While in our work, the design of the cuvette holder and the use of quartz cuvette helped us to ensure the emitting of light on the sample without the need for any external optical fiber or lens; moreover, they did not include their final device package to see how they controlled light leakage or scattering. They used their system for analyzing water contents and did not mention the possibility of using it for other types of liquids.

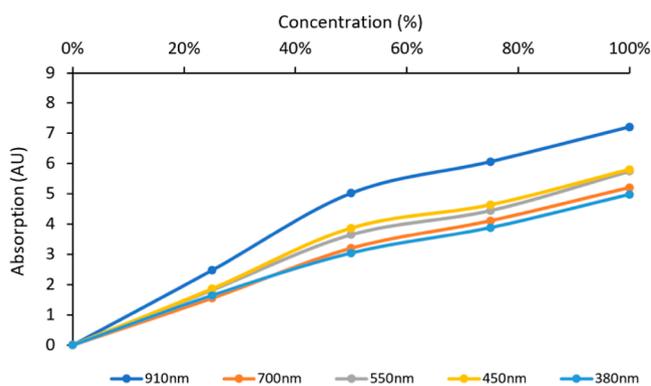


Figure 7. Pomegranate molasses absorption vs concentration.

The system published by Bano et al.¹² was used to measure KMnO_4 at different concentrations using Beer–Lambert law. They needed to use a compact disc (CD) media as a diffraction grid and a moving slit along with stepper motor for obtaining a monochromatic light. In our opinion, the spectrophotometer they proposed show many sources of light leakage and scattering. The circuit board they included does not guarantee correct light emission on the sample and their proposed system shows that they have done the measurements in an open air. The optical readings need to be collected in a closed and shielded system to give correct repeatable results. In our design, we have a closed system that considered leakage and scattering prevention, and we did not need to use any diffraction grid.

Moreover, Han et al.²⁷ have used only 235 and 275 nm light-emitting diodes (LEDs) as the light sources, which limit the selectivity of their device, and they used their system for measuring nitrate concentration in water, but not to identify different liquids.

While the colorimetric sensor devised by Xing et al.³⁰ successfully achieved simultaneous detection of various waterborne pollutants with heightened precision and reliability, their approach required the incorporation of a diffraction grating to divide six white beams traversing multiple colored samples. This design element rendered their solution more costly and intricate compared to our approach. Furthermore, their utilization of the sensor was confined to water quality assessment alone, failing to acknowledge its potential applicability to broader contexts. This suggests that the wavelength range employed might be insufficient for distinguishing different liquid types beyond water.

4. CONCLUSIONS AND FUTURE WORK

This paper presents the development of a portable device that can be used for liquid identification using the concept of Beer–Lambert law. The final device can recognize up to 30 different materials in their liquid state and provide some other useful features that can enhance its operation. In future, more wavelengths of light will be added to increase the selectivity of the device and reduce the error in measuring different liquids. Furthermore, because the sample absorbance depends on its concentration, this device is capable of providing different absorbances at different concentrations, which makes it useful for determining the concentration of a specific sample. The device will be used to measure a liquid at different concentrations, and the results will be used to calibrate other

sensors operating in different technologies, such as electrochemical sensors.

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Notes

The authors declare no competing financial interest.

All data generated or analyzed during this study are included in this published article (Tables and figures). This type of research is an applied research, we did not use external datasets, and we have done experiments in the lab and collect data for different samples; and these samples are not necessarily the only samples that can be measured.

Accordance Statement: All the methods applied in this work were carried out in accordance to relevant local/national/international guidelines and regulations.

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