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Real-time Monitoring of the Environment Gases within the UV-NIR Regions

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الكشف المباشر للغازات البيئية ضمن مناطق الأشعة فوق البنفسجية وتحت الحمراء القريبة

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ABSTRACT

Indoor air quality and environmental monitoring, particularly during the coronavirus (COVID-19) pandemic are vital and in need. The main purpose of monitoring the air quality is that the infected area may increase the risk of spreading infectious diseases of COVID-19. Therefore, real-time and non-contact measurements are more necessary for the current situation to monitor the indoor area air quality. In this study, we propose an optical method for monitoring indoor air quality in fast and accurate tracking of ultraviolet (UV), visible, and near-infrared (IR) indoor atmospheric gases using the natural sunlight and spectrometer. The proposed method is portable, non-contact, and real-time spectroscopy screening of the Oxygen (O_2), Ozone (O_3), and water vapour through the analysis of their absorption characteristics. The absorption peaks and light intensities of O_2 at 630 nm, 685 nm, and 758; O_3 at 380 nm, 390 nm, 427 nm, 481 nm, 522 nm; and H_2O at 718 nm and 820 nm have been monitored at different weather conditions. Further to provide air pollution's effect through tracking the absorption peaks and intensity for each gas, the proposed method might help identify the infected area potential of COVID-19 under practical scenarios such as pre-inspection in houses, shops, hospitals, and schools. The data are of great importance, particularly for population groups and individuals most vulnerable to COVID-19. Considering factors such as safety, stability, and price, this simple technology is the most suitable for real applications.

Keywords: Air Quality, Environmental Monitoring, COVID-19, Air Quality, Atmospheric Gases.

الملخص

تعدُّ جودة الهواء الداخلي ومراقبة التأثيرات البيئية، لا سيما أثناء جائحة فيروس كورونا (COVID-19) أمرًا حيويًا وضرورياً. فالغرض الرئيسي من مراقبة جودة الهواء هو أن المنطقة المصابة قد تزيد من خطر انتشار الأمراض المعدية لـ COVID-19. لذلك، تعد تقانة الكشف اللحظي والمباشر مع عدم الاتصال ضروري لمراقبة جودة الهواء في المناطق المغلقة. في هذه الدراسة، نقترح طريقة بصرية لمراقبة جودة الهواء الداخلي من خلال التتبع السريع والدقيق للغازات الجوية ضمن منطقة الأشعة فوق البنفسجية (UV) والمرئية والقريبة من الأشعة تحت الحمراء (IR) باستخدام ضوء الشمس الطبيعي ومقياس الطيف. الطريقة المقترحة هي الفحص الطيفي المحمول مع عدم الاتصال واللحظي المباشر للأوكسجين (O_2) والأوزون (O_3) وبخار الماء من خلال تحليل خصائص الامتصاص الخاصة بهذه الغازات. قمم الامتصاص وشدة الضوء لـ O_2 عند 630 نانومتر و 685 نانومتر و 758 ؛ O_3 عند 380 نانومتر، 390 نانومتر، 427 نانومتر، 481 نانومتر، 522 نانومتر؛ و H_2O عند 718 نانومتر و 820 نانومتر تم رصدها في ظروف جوية مختلفة. علاوة على توفير تأثير تلوث الهواء من خلال تتبع قمم الامتصاص وكثافة كل غاز، قد تساعد الطريقة المقترحة في تحديد المنطقة المصابة المحتملة بفايروس كورونا-19 في ظل سيناريوهات عملية مثل الفحص المسبق في المنازل والمتاجر والمستشفيات والمدارس. البيانات ذات أهمية كبيرة، لا سيما بالنسبة للمجموعات السكانية والأفراد الأكثر عرضة لـ للإصابة بالفايروس. بالنظر إلى عوامل مثل الأمان والاستقرار والكلفة، فإن هذه التقنية البسيطة هي الأنسب للتطبيقات الحقيقية.

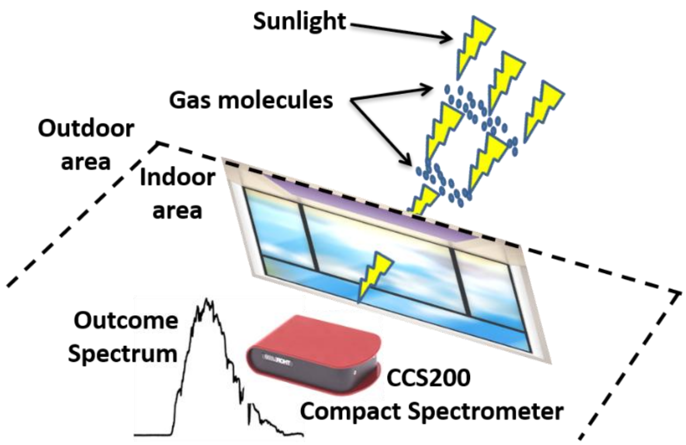
1. Introduction.

Further to the general sources of air pollution, air pollution infected with COVID-19 has recently become an issue of worldwide concern because of the serious health and environmental impact on humans. So, air monitoring in indoor places such as schools, airports, shops, houses, etc., and some other places are essential nowadays. It is now well established that screening particular trace gases such as Oxygen (O_2) and Ozone (O_3) in the air at ground level or indoors can provide information about the air pollution that can cause significant adverse health effects and damage to the environment. Unlike in monitoring the changing atmosphere such as carbon dioxide (CO_2) and methane (CH_4) levels that cause climate change, monitoring other gases such as O_2 and O_3 has become needful nowadays for monitoring the air quality. For this reason, atmospheric O_2 and O_3 measurements can be used, especially, to monitor the indoor area. However, we believe that as long as climate change had affected the O_2 air level, COVID-19 will also lead to small variations in O_2 and O_3 peaks absorption which could be challenging for traditional electronic air quality sensors to detect the contaminated area. Moreover, an advantage of optical atmospheric measurements is that the observation of O_2 and O_3, as well as other gases within UV-NIR of the electromagnetic spectrum, can be used to derive the path lengths of photons through the infected area and hence could contribute to the anomalous absorption effect in these gases. On one hand, studying atmospheric chemistry with the visible portion of the spectrum is not new, it has been used for measuring gases through the detection of molecular absorption features [1-4]. Measuring O_2 was developed using mass spectrometry [5], a paramagnetic analyzer [6], vacuum ultraviolet absorption [7], gas chromatography [8], fuel cells [9], and also using continuous on-site measurements [10-12]. Therefore, accurate and highly precise atmospheric O_2 measurements offer a significant contribution to a better understanding of the global carbon cycle [13-14]. On the other hand, a detailed and quantitative analysis has been studied in [15-19], highlighting the impact of COVID-19 on people's lives, activities, research production and the environment. It also found that there are ten scientific reasons in support of the airborne transmission of COVID-19 [20]. Moreover, citizens' responses to the policies enacted to control the disease have also been studied [15-18].

But there is limited research on the impact of virus mitigation and containment measures on the environment and air quality. From our perspective, we believe the level of air quality is a result of robust interactions with the COVID-19 pollutants. This is supported by a recent study using light of night imaging techniques [17] to predict the spreading of COVID-19 in the air and environment. Therefore, this study aims to assist with providing the technology that can help with understanding the behavior of gases to detect the contaminated area, hence leading to the disinfection of it and curbing the spread of the virus epidemic in both indoor and outdoor environments. The proposed technology is a compact, real-time, low-cost, and high-precision UV to NIR spectroscopy technique for monitoring air quality. This technique provides details and describes the unique features of gases within the UV to NIR regime, particularly, O_2 and O_3 within indoor/outdoor environments; the performance of the peak absorptions and light intensities of these gases have been evaluated in this work, based on various independent laboratory weather conditions.

2. Methodology and Data Collection.

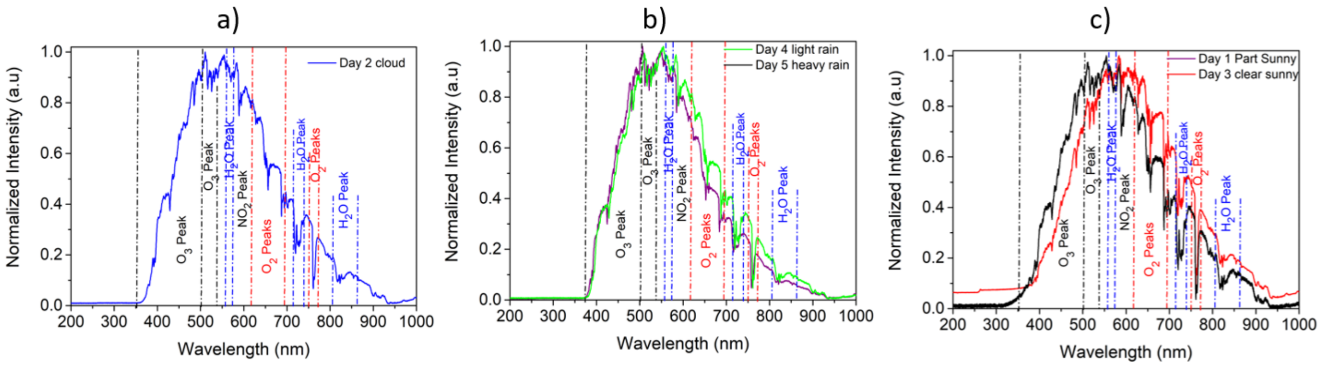
The methodology that has been used in this study is focusing on the monitoring of UV, visible, and NIR indoor atmospheric trace gases, particularly O_2 and O_3 gases using spectroscopy absorption of the gases within the regions of 200-1000 nm. In this study, the light source can be any, such as the natural sunlight radiation as in our study (Fig. 1) or any other light sources such as light emitted diode (LED), tungsten lamp, etc. As illustrated in the schematic of Fig. 1, the sunlight is passing through a glass window to examine the indoor/outdoor room or hall. The transmitted light that interacted with indoor gasses in the room is collected by using an optical spectrum analyzer (OSA) which is placed at a 2 m distance from the window at an angle of 45 degrees and altitude of 1.5 m. The OSA (CCS200-compact CCD spectrometer) instrument that has been used in this research has a spectral resolution of 0.2 nm allowing a clear distinction between gases contributions to the observed absorption in the 200-1000 nm spectral region. Hence providing a stringent test of the quality of the observed gases features particularly O_2 and O_3 bands as well as the nearby overtone bands of water vapour (H_2O). The data was recorded at various weather conditions among five sets of light and heavy rain, cloud, and clear and partly sunny sky conditions weathers. For each single weather condition, the average of different three days' measurements has been presented. The collected data that includes different weather conditions have been chosen because the UV-NIR regions of the spectrum apparently display the largest discrepancies between observations and theory in these conditions and hence are subjects of particular scrutiny therein. Furthermore, the indoor laboratory measurements of UV-NIR (200–1000 nm) absorption of O_2 and O_3 gases, as well as other gases, are critically monitored and reviewed, taking into account the variation of the weather conditions. Therefore, in this study, comprehensive laboratory data have been taken into the consideration during the spectra measurements in order to monitor in real-time the O_2, $O_{3,}$ and H_2O gases and hence assess the spectral peaks absorption wavelength position and normalized intensity within UV-NIR reign. This method of O_2 and O_3 gas monitoring based on spectral instruments is an accurate, easy, and cheap real-time tool to provide the necessary data as we can be called an air oximeter.



Figure(1): The spectroscopy setup using natural sunlight source radiation for monitoring the environment gases within UV-NIR regions.

3. Results and discussions

The absorption of UV-NIR radiation in various weather conditions is a key factor in air pollution detection. Besides the improved accuracy of the environment's gases measurements that result from the sun's broad spectral coverage at high resolution, real-time detection of the air pollutions may be possible via monitoring the O_2 and O_3 profile using full spectral information in the 200-1000 nm regions. The transmitted sunlight that interacted with environmental gases has been considered at different weather conditions and high resolution (0.2 nm) over a wide range of wavelengths as shown in Fig. 2 which summarizes the major absorption features of environmental gases and their complexes in the wavelength range from 200-to 1000-nm. Different weather conditions have been used for better understanding the absorption cross-section and comparing the peak absorption wavelength and the transmitted intensities of environmental gases within this region of the electromagnetic spectrum at weather conditions of cloud (Fig.2 a); light and heavy rains (Fig.2 b); and clear and part sunny (Fig.2 c), hence identifying the anomalous absorption. The results have been assessed based on monitoring the position of the gases' absorption wavelength peaks and their intensities. All observed wavelength absorption of the gases in the bands of 200- 1000 nm are shown in Fig. 2 agreed well with their expected spectral structure under all five weather conditions. The observed structured absorption in this wide wavelength range could be accounted by considering the O_2, O_3, and H_2O trace gases under the aforementioned weather conditions.



Figure(2): Absorption features of environmental gases using the solar radiation, indoor area at the approximate wavelength regions of 200-1000 nm at different weather conditions; a) cloud; b) light and heavy rains; and c) clear and partly sunny.

In the UV region (200-400 nm), the main absorbers are molecular O_3. So, the O_3 absorption exhibits two continua peaks at 380 nm and 390 nm named Huggins bands [21] which appeared due to the photo-dissociation. These absorption peaks are quite higher than the other small absorption band in the region between 240-300nm (Hartley band) [21] which are mainly absorbed in the stratosphere and mesosphere.

In the visible region (400-700 nm), the absorption peaks at around 427 nm, 481 nm, and two neighboured peaks around 522 nm are appeared due to the O_3 molecular absorption (blue tail of the Chappuis band), while the high absorption peaks at around 630 nm (γ band), 655 nm and 685nm (B-band) appeared due to the O_2 molecular absorption [21]. In the NIR region (700-1000nm), there are some interesting absorption peaks, the peak at 758 nm is also belongs to the O_2 (A-band) absorption wavelength which is mainly used for the remote sensing of the level of cloud pressure from space. Strong absorption peaks and combination bands centred at 718 nm and 820 nm have also been observed and are related to the H_2O vapour absorption [22]. These two peaks are supposed to be relatively weak, but the high absorption here could be due to the high humidity in the United Kingdom weather. The contribution of H_2O to the solar heating of the atmosphere appears to be significant. Several quite small H_2O lines have also been detected in the visible region that is associated with combination transitions. However, molecular O_2 that has absorption bands in the visible and NIR designated by the two excited states A and B transitions coupled with vibrational–rotational transitions produce weak absorption lines in the visible and NIR, respectively.

Clear absorption peaks in the visible region have been expected to detect in the visible region which is related to the nitrogen dioxide (NO_2) [23], but only one peak at 589 nm is related to this gas in the region. The absence of other peaks is due to low pressure and temperature which both influence the absorption of this gas [24]. Additionally, due to the complexity of the excited electronic states of this gas, it is impossible to predict its spectrum from NO_2 molecular even with high experimental resolution.

After analyzing the collected data, the peak wavelengths of all the observed gases in the region of 200 nm-1000 nm have been monitored and it was found that all peaks are approximately in the same position for most days under investigation weather conditions as shown in Fig. 3, with small wavelength fluctuation (1nm) have noticed due to weather temperature variation. The normalized transmitted intensity of the absorption peaks was also examined on different weather days for O_3, O_2, and H_2O gases as illustrated in Fig. 4. The normalized intensity has clear fluctuations across the days for each wavelength's peak. For instance, on day 3 in Fig. 4-a where the weather is clear sunny, O_3 (427 nm, 481 nm, and 522 nm) has a lower normalized intensity that led to an increase of the intensity of O_2 (630 nm, 655 nm, 685 nm, and 758 nm) and H_2O gases (718 nm and 820 nm) in Fig. 4-b. This means that the high temperature disrupts the band of the O_3 molecule in the visible region and converts it back to O_2 and H_2O where the intensities of these gases were increased. Also, on the clear sunny day (red color in Fig. 2), the spectrum has a redshift due to the high temperature (+15C) of that day compared to all other days.

So, any observations for the anomalous absorption in the region of 200-1000 nm may indeed be related not only to structured features but rather to various pollutions. O_2, $O_{3,}$ and H_2O all play a vital role in anomalous absorption, which could lead to a weak spectral structure (or lack thereof) of absorption. Therefore, the O_2 and O_3 may be affected by the COVID-19 interactions which will lead to anomalous behaviour in these gases' absorption peaks leading to exchange yields (light-virus interactions) that provide valuable information about the contaminated area (pollutions) and uptake, which cannot be acquired from other measurements. Therefore, this spectroscopic technique is an ideal method for monitoring atmospheric O_2 and O_3 indoor background levels and studying these gases-air interactions. This technique can also be extended beyond the daytime sunlight to include an outdoor bust area using streetlights to monitor air quality at night.

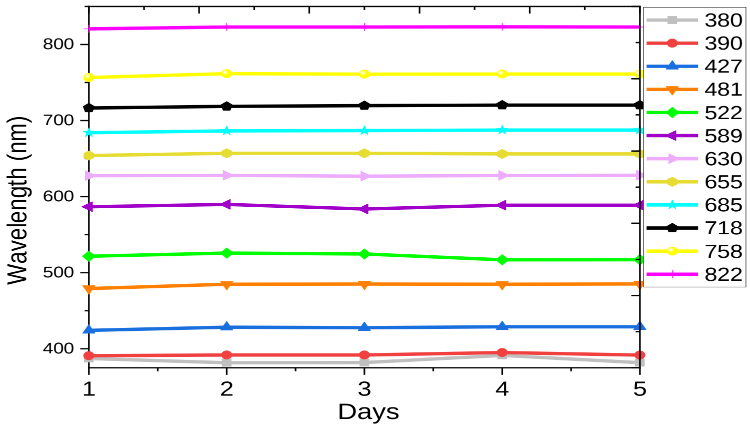
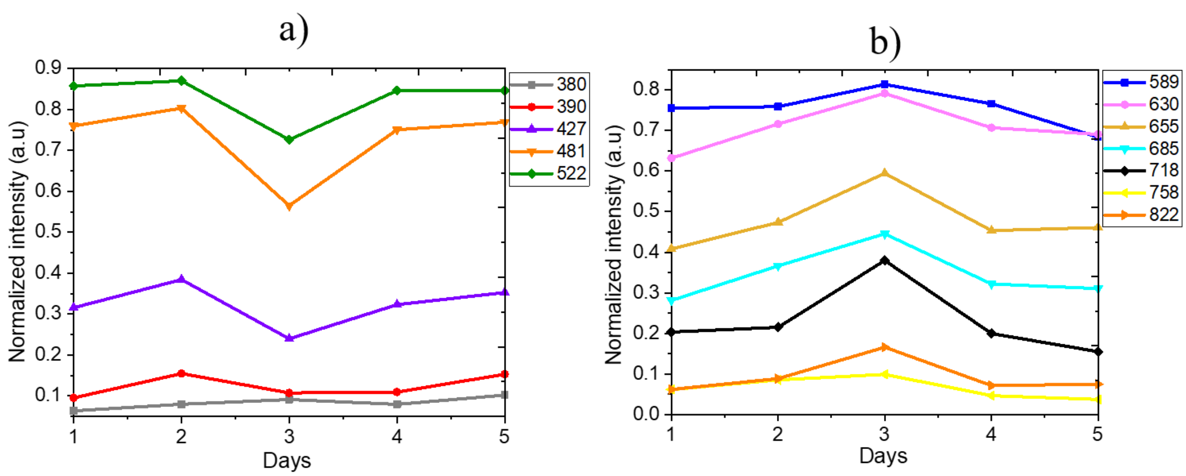


Figure (3): The absorption gases wavelength peaks on different weather days.



Figuer(4): The normalized intensity of the absorption peaks on different weather days for a) O_3 and b) O_2 and H_2O.

4. Conclusions.

We demonstrated a real-time and non-contact optical absorption method for monitoring gases within 200-1000 nm, particularly, O_2, H_2O, and O_3 for monitoring indoor air quality. Using this technique, many peaks of O_2, $O_{3,}$ and H_2O have been observed and monitored at different weather conditions. The peak wavelengths for all of the observed gases are approximately located at the same position for most days under investigation weather conditions, whereas the normalized transmitted intensities have clear fluctuations across the days for each wavelength's peak due to disrupts the band of O_3 molecule in the visible region and convert it back to O_2 and H_2O at hot weather. Further to the simple and low cost, this method is fast and allows accurate retrieval of UV, visible, and NIR indoor atmospheric trace gases using the natural sunlight and absorption spectrometer. Moreover, the method is also can be adaptable to connect with smart mobile and computers to provide a portable analyzing system for the monitoring of the air quality especially in the time of the COVID-19 pandemic.

List of abbreviations

1	CCD	Charged coupled device
2	CH_4	methane
3	CO_2	carbon dioxide
4	COVID-19	Coronavirus-2019
5	H_2O	water vapour
6	IR	near-infrared
7	LED	light emitted diode
8	NO_2	Nitrogen Dioxide
9	OSA	optical spectrum analyzer
10	O_2	Oxygen
11	O_3	Ozone
12	UV	ultraviolet

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