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Design and Construction of a Dust Detection System using Infrared Laser: The Case of Dust Storms in Baghdad in the Summer 2022

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Abstract
Iraq suffers from serious pollution with harmful particles that have important direct and indirect effects on human activities and human health. In this research, a system for detecting pollutants in the air was designed and manufactured using infrared laser technology. This system was used to detect the presence of pollutants in the dust storms that swept the city of Baghdad which could have a negative impact on human health and living organisms.

The designed detection system based on the use of infrared laser (IR) with a wavelength of 1064 nm was used for the purposes of detecting pollutants based on the scattering of the laser beam from these pollutants. The system was aligned to obtain the best signal for the scattered rays, which were detected using a digital storage oscilloscope.

These studies were conducted during the dust storms that occurred intensely in Baghdad in the months (April, May, June and July) of the year 2022. Where multiple samples were taken at different periods in these storms, measurements were also done during the storm. The types of polluting elements found in the dust of the storms are: carbon, bromine, chlorine, hydrocarbons alcohol, ether, hydroxyl group, carbon, C=C (aromatic ring), nitrogen dioxide (aromatic nitro), and carbon monoxide. The value of dust pollutant concentrations is (125.67 mg. m^{-3}).

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1. Introduction
Air is a mixture of gases and suspended particles of various sizes. This chemical composition is in a state of continuous change that affects space and time due to physical quality and many chemical reactions. Air is one of the most important environmental media; it contributes significantly to the transfer and spread of pollutants in gaseous and suspended particle forms [1].

Air pollution is a hassle in the growing world and is the cause of increased deaths worldwide, more than that caused by malaria, breast cancer, or tuberculosis. Airborne particles are particularly harmful to health, causing exacerbating respiratory and cardiac disease, and have previously been estimated to purpose between 3 and 7 million deaths each year. Sources of these pollutant particles include electric plants, industrial facilities, vehicle burning, biomass burning, oil refineries, fossil fuels used in homes and factories for heating, and dust storms [2]. Recently, Iraq witnessed many dust storms due to the desertification of Iraq and its neighboring countries, Syria and Iran. These storms contain crusty materials (dust), which cause health problems in the Middle East and other desert regions [3, 4].

Dust is defined as a mixture of liquid or solid particles or a mixture of them, whose diameters vary greatly and is finer than sand. There are many types of air polluting dust, for example [5]:

1- Suspended dust whose particles remain suspended in the air and fall due to gravity at varying rates according to the weight and size of these particles.
2- Accumulated dust which is particles of dust that soon return to the earth due to the earth's gravity after its launch.

Dust has important direct and indirect effects on human activities. Recent research focuses on the health effects of air pollution and its contribution to higher mortality and morbidity rates, including heart and blood vessels and respiratory disease, exacerbation of chronic respiratory disease and decreased lung function, upon short-term exposure to air pollution [6]. Because of the decline in air quality in recent years in Iraq after 2003 and the frequent dust storms due to desertification, the presence of these suspended particles in the air has become a source of danger. As a result, much research has been conducted to monitor air quality and identify its sources. Its harmful elements have been determined using laser beams which proved its success in detecting air pollutants [7].

Laser spectrum analysis is used to detect the types of elements in the air and calculate the concentration of atmospheric pollutants by calculating the attenuation of the laser beam as well as finding the spectrum of the rays passing through the polluted air. Laser is used in these applications because the spread of the laser beam in the atmosphere is important to determine the extent of the loss of the rays during their propagation. The transmission of laser rays in the atmosphere is a complex process as it is affected by absorption and scattering factors and by atmospheric conditions such as humidity, temperature, and dust particles. The air will absorb or scatter a portion of the laser beam as wavelengths are attenuated. Therefore, a laser beam with a suitable wavelength was chosen in this work so as to reduce the losses caused by absorption and scattering [8].

In this research, a system for detecting pollutants in the air was designed and manufactured using IR laser technology. This system was used to detect the presence of pollutants in the dust storms that swept the city of Baghdad in the summer of 2022 and to know their harmful effects and health damages on humans and living organisms. It describes the analysis of the laser beam after passing through polluted air at different times for measurement. This paper also introduces concepts of profile analysis of the laser beam based on image processing methods to measure the laser spot profile and pollutant distribution. The system that was manufactured showed that the detection can be done easily and in a short time, as well as the possibility of knowing the types of pollutants and their concentrations.

2. Theory

The Atmospheric air contains particles of different sizes, sources and chemical compositions and they are spread over a large distance. The concentrations of these particles decrease with the increase of altitude from the surface of the earth. These particles are suspended in the atmosphere and considered as good dispersal materials. These particles scatter the laser beam away from its direction of propagation, which means that the laser beam is attenuated. The total attenuation and the amount of beam change depends on the characteristics of the atmosphere and the output power of the laser beam, used to detect pollutants, which is subjected to absorption and scattering phenomena due to the influence of polluted air [9].

Atmospheric attenuation is defined as the process by which some or all of the energy of an electromagnetic wave is lost as it passes through the atmosphere. The laser beam interacts with polluting materials in two ways [10]:

1- Absorption: The process of absorption by air pollutants is one of the most important processes in the loss of laser ray energy during its spread in the atmosphere. Where each gas molecule has its own absorption spectrum that is different from the other. The principle of detection depends on the difference in the absorption power of the laser at different wavelengths.

The absorption coefficient depends on the types of gas molecules and their concentration. The amount of transmitted radiation decreases with the increase in the thickness of the material through which the radiation passes [9].

The concentration of pollutants was calculated from the following relation [8]:

$$C = \frac{5.2\rho r}{V_{op}\,k}\ [\mathrm{mg.m^{-3}}] \qquad (1)$$

where: density (ρ) is about 1.69×10^{9} mg.m^{-3}, particle radius (r) is 5.56×10^{-9} km, visibility (V_{op}) is in m, and scattering area coefficient (K) is about 2 for dust particles.

The visibility distance (V_{op}) can be calculated from the following relationship [11]:

$$V_{op} = \frac{2.996\,D}{\ln T_{att}} \qquad (2)$$

where: D is the distance between the transmitter and receiver (laser source and detector) and T_{att} is atmospheric transmittance.

The atmospheric transmittance T_{att} can be calculated from [11]:

$$T_{att} = \frac{P_{in}}{P_o} \qquad (3)$$

where: P_{in} is the power of the emitted and incident laser beam on the examination cell, which is equal to 1.2 mW for the infrared laser used. And P_{out} 0.816 mW in the power of the laser coming out of the cell, which is detected by the detector.

2- Scattering: occurs with particles randomly moving with respect to each other. If the light is scattered by ordered particles, it can cause phenomena such as reflection, refraction or diffraction.

Both of the above interactions attenuate the light beam when passing through these particles [10].

The main difference between scattering and absorption is that in scattering there is no loss of intensity as happens in the absorption processes, but there is a change in the direction and shape of the wavelength only [12]. In scattering, suspended particles located in the path of the rays absorb electromagnetic energy and then radiate that energy in all directions, that is, the light is scattered when it collides with very small particles in the air.

The scattering is divided into two main parts [12]:

a- Elastic scattering, which does not change the energy of the resulting photon, such as Mie scattering, Rayleigh scattering and non-selective scattering.

b- Inelastic scattering, which produces photons with energy different from the energy of the incident photon such as Raman scattering and Brillion scattering.

A beam of radiation is scattered in a range of directions as a result of physical interactions. When a particle intercepts an electromagnetic wave, part of the wave's energy is removed by the particle and reradiated to a solid angle centered around it. The scattered light is polarized and has the same wavelength as the incident beam, which means that there is no energy loss in the particle [13].

The type of scattering that most commonly occurs when laser rays fall on dust particles is Mie scattering, which is a type of elastic scattering. Mie scattering occurs when the diameter of the scattering particles is equal to the wavelength of the incident light. Mie scattering is produced by pollen, dust, and smoke. In this type of scattering dispersion occurs by particle where the particle presents a large forward lobe and small side lobes that begin to appear as shown in Fig. 1. Raman spectroscopy was used to measure and identify the organic compounds present in the dust [13].

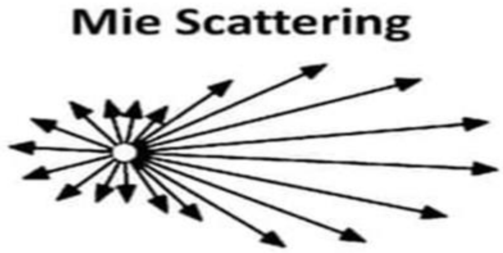

Figure 1: Shapes of Mie scattering according to particle size [13].

3. Instrumentation and Experiments

The details of the experimental setup and the method for extracting aerosol information from laser returned signals are briefly discussed in this section. The system consists of a physical-optical model, a 130 mW IR laser with a wavelength of 1064 nm (model: MIL-III-1064, Origin China) as a transmitter. An optical chopper (THORLABS model: MC2000 origin USA) was used to cut the IR laser beam to convert it into a pulsed laser. A rectangular glass cell was built in dimensions of 7.7×2.5×2.5 cm^3, which contains the samples of the pollutant air. The laser beam was passed through this dust-contaminated cell, where it would suffer scattering by the dust particles. This led to a difference between the incident laser intensity and the transmitted through the cell. The penetrated laser was detected by an optical detector (phototransistor type 3DU33, origin China) with a digital storage oscilloscope (ADS1102CAL from ATTEWN company, China) to display the shape of the pulse of the penetrating laser after it collided with dust pollutants. Fig. 2 shows the pollution measurement system using a laser beam.

Fig.3 shows the system that was designed and built in the laboratory, which was used to detect air pollutants.

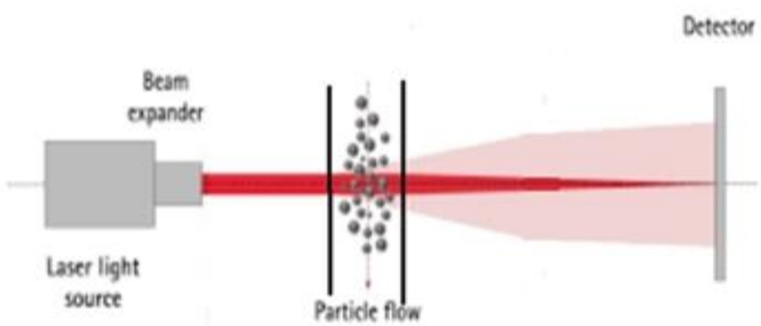

Figure 2: Simplified diagram of the pollutant detection system.

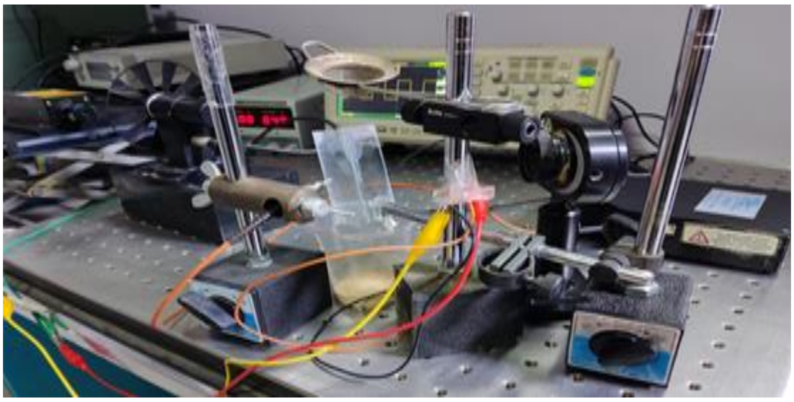

Figure 3: The system designed to detect dust pollutants.

4. Results and Discussion

Measurements were made in the dust storms that swept the city of Baghdad in the summer of 2022. Dust samples were taken from these storms, where measurements were made using the designed system also measurements were done at the time of the storms. Dust samples, of two diameters, 11.11 and 3.7 micrometer were taken from these storms. The size was determined using an optical microscope.

Fig.4 shows the variation of the power of IR laser with the thickness of the glass used to attenuate the rays to get the best signal, which leads to change in the absorption coefficient (δ). It is clear from this figure that the power decreases as the thickness increases. It can be noted, from the figure, that the lowest energy of the laser beam that can detect the pollutants is 11.15 mW at 25 mm glass thickness. This thickness was chosen to give the best results for detecting contamination.

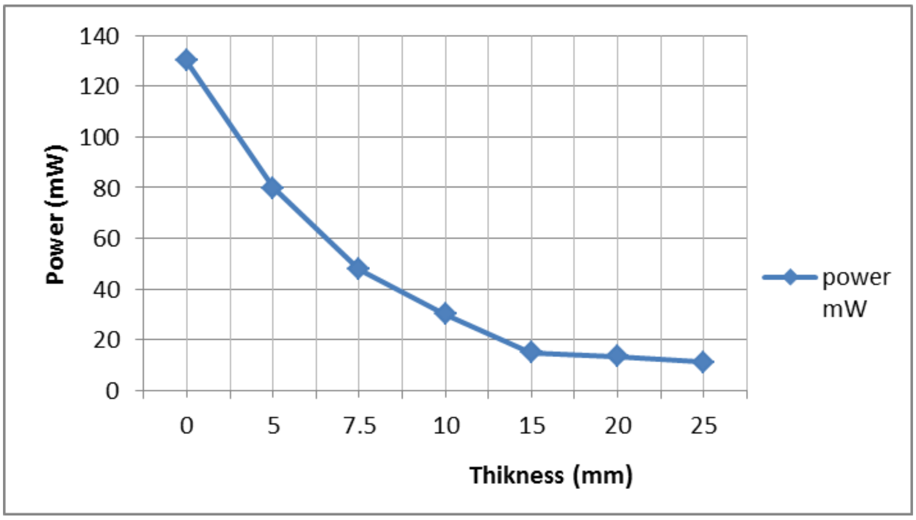

Figure 4: Relationship between laser power and glass thickness.

The oscilloscope was used detect the pulse shape and to measure the effect of dust in the path of the laser beam, on the pulse shape. The pulses seen on the screen of the oscilloscope, illustrated in Fig. 5 (where the X-axis represents the time (t), and the Y-axis represents the laser power (P)), clearly showed the change in shape due to scattering caused by the dust particles. It can be noted that the change is greater in the case of coarse dust particles; this is because the probability of scattering is greater in the case of a large number of particles with large sizes. A decrease in the power of the laser beam penetrating out of the dust cell was also noted. The results noted were as follows:

1. Pulse shape without pollutants of dust particles, laser power appeared at (1.2 mW).
2. For fine dust particles, laser power appeared at (0.816 mW).
3. For coarse dust particles, laser power appeared at (0.7008 mW).

From Eq.(3), the atmospheric transmittance was calculated, which was 1.47 for the fine dust particles, and 1.71 for the coarse dust particles.

The spectrum of dust pollutants was analyzed with a spectral analyzer (Type Ocean 2000). The pollutants were detected and identified according to the wavelength as shown in Fig.6. From the figure, the elements shown in Table 1 were identified:

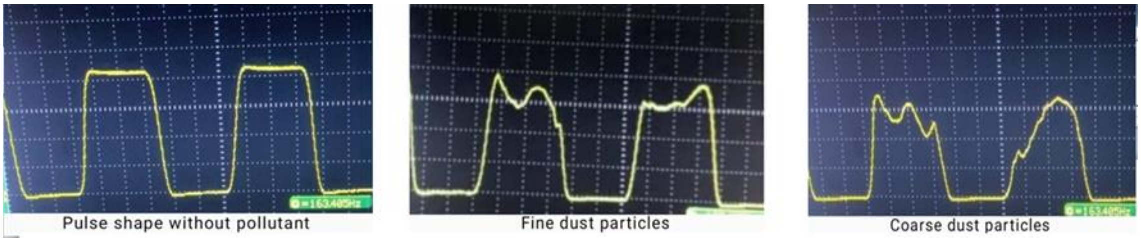

Figure 5: Pulse shape a- without pollutants, b-fine dust particles, c-coarse dust particles.

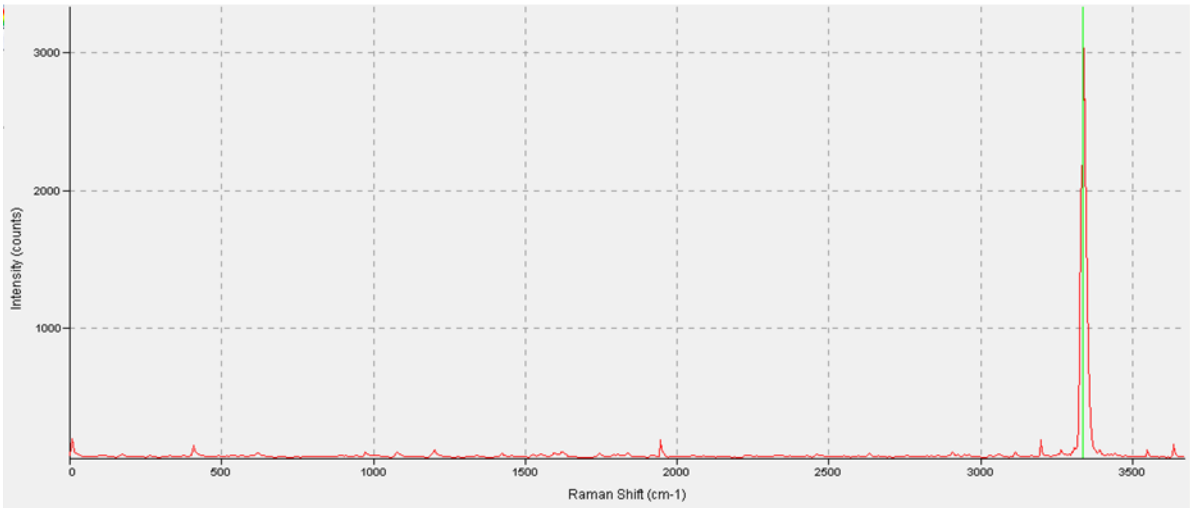

Figure 6: Absorption spectrum of dust pollutants.

Table 1: Polluted elements by wavelength.

Raman shifting cm^{-1}	**Elements**
414	carbon, bromine
624	chlorine
906	hydrocarbons
1080	alcohol, ether
1424	hydroxyl group, carbon
1550	C=C (aromatic ring), nitrogen dioxide (aromatic nitro)
1742	carbon monoxide

These detected elements cause great harm to humans, especially those with respiratory problems, and living organisms [14].

Fig.7 shows two and three-dimensional images of the dust concentrations in the cell using Charge Coupled Device (CCD Cameras). The manufacture company is Gentec Electro-Optics and it is made in Canada. The figure shows that there are random gatherings and irregularities in the distribution of the dust particles.

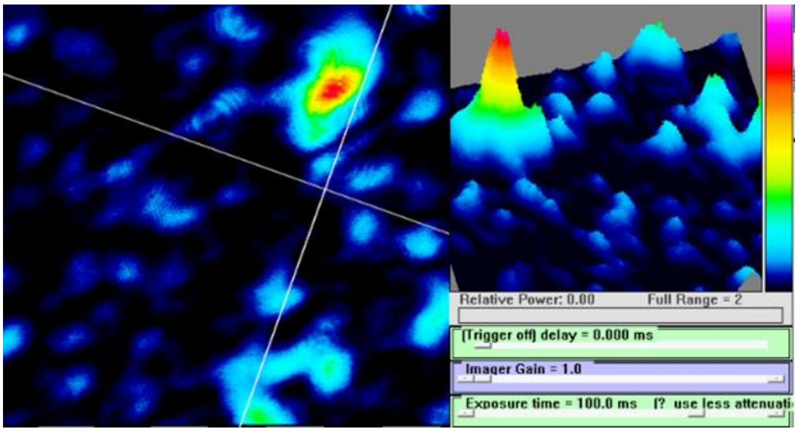

Figure 7: The concentrations of dust pollutants.

Compared to previous works, the current work is distinguished by its ability to easily detect the types of pollutants and their chemical compositions, in addition to finding concentrations of pollutants and images in two and three dimensions of pollutants profile. Yu et al. [15] designed and built a system to detect dust and its concentration in the atmosphere, using laser beams depending on Mie scattering. Also, Al-Jarakh et al. [16] conducted a study on the effects of dust concentrations throughout Iraq, using different types of sensors.

The advantage of this research is that, it was conducted at the time of the storm in addition to collecting samples from the dust left by these storms to detect the pollutants and determine their types and concentrations quickly, easily, accurately and in real time.

5. Conclusions

A system was designed and built to detect the dust in the air and identify its components using laser technology. This system gave good results for calculating the attenuation and change of the power of the laser beam passing through polluted air due to the effect of dust; through these factors, the dust concentration was calculated. These results were close to those obtained using a measuring device type (PM2.5).

Two and three-dimensional images were obtained showing the dust concentration in the air, which was identical to that of the microscope image. The types of dust pollutants were identified using the spectroscopic technique associated with the designed system. The elements detected are known to be harmful to the respiratory system of humans and other living organisms.

Acknowledgments

I extend my sincere thanks to the Iraqi Ministry of Science and Technology department of Laser and Optics, where the system was designed and built, and all experiments were conducted in the Ministry's laboratories.

Conflict of interest

Authors declare that they have no conflict of interest.

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تصميم وبناء منظومة كشف الاتربة باستخدام ليزر الاشعة تحت الحمراء: حالة العواصف الترابية في بغداد لعام 2022

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الخلاصة

يعاني العراق من تلوث خطير بجزيئات ضارة لها آثار مهمة مباشرة وغير مباشرة على أنشطة الإنسان وصحته. في هذا البحث، تم تصميم وتصنيع نظام للكشف عن الملوثات في الهواء باستخدام تقنية الليزر بالأشعة تحت الحمراء. تم استخدام هذا النظام للكشف عن وجود ملوثات في العواصف الترابية التي اجتاحت مدينة بغداد والتي يمكن أن يكون لها تأثير سلبي على صحة الإنسان والكائنات الحية.

وتم استخدام نظام الكشف المصمم القائم على استخدام ليزر الأشعة تحت الحمراء (IR) بطول موجي 1064 نانومتر لأغراض الكشف عن الملوثات بناء على تشتت شعاع الليزر من هذه الملوثات. حيث تمت محاذاة النظام للحصول على أفضل إشارة للأشعة المتناثرة، والتي تم كشفها باستخدام راسم الذبذبات للتخزين الرقمي.

وأجريت هذه الدراسات خلال العواصف الترابية التي حدثت بشكل مكثف في بغداد في أشهر (نيسان وأيار وحزيران وتموز) من العام 2022. تم أخذ عينات متعددة في فترات مختلفة في هذه العواصف، كما تم إجراء قياسات أثناء العاصفة. أنواع العناصر الملوثة الموجودة في غبار العواصف هي: الكربون، البروم، الكلور، كحول الهيدروكربونات، الأثير، مجموعة الهيدروكسيل، الكربون، C = C (الحلقة العطرية)، ثاني أوكسيد النيتروجين (نيترو عطري)، وأول أكسيد الكربون. حيث تم حساب قيمة تراكيز ملوثات الغبار (125.67ملغ م$^{-3}$).