Optical Forward Scattering Property Employment for measuring the Atmospheric Visibility

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Abstract
An optoelectronic system for fog detection and visibility technique is presented .The idea of this research is based on the measurement of the atmospheric visibility by using an infrared beam emitter from LED diode. The optical scattering is used as a method to calculate the visibility. This method is applied at forward scattering within a foggy atmosphere, which is modern and has great importance for measuring visibility in seaports, airports, public roads and highways. In this paper we focus on the description of the system, principles of its operation and some results of field tests.

Keywords: fog sensor, visibility sensor, backscattering, forward scattering.

توظيف خاصية الاستطارة الأمامية الضوئية لقياس مدى الرؤية للجو

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الخلاصة
تستند فكرة البحث على نظام كهروبصري لكشف وقياس مدى الرؤية للجو الضبابي باستخدام الأشعة تحت الحمراء المنبعثة من ثنائي بلوري وباستخدام تقنية الاستطارة البصرية.حيث تم التركيز على الاستطارة الأمامية لحساب مدى الرؤية ضمن أجواء ضبابية،هذه التقنية ذات أهمية كبيرة وحديثة لقياس مدى الرؤية في الموانئ البحرية والمطارات الجوية والطرق العامة والسريعة. كان تركيزنا في هذا البحث على وصف النظام ومبادئ العمل وبعض النتائج المختبرية .

1. Introduction

The clear visibility of the environment is very important in all kinds of mobility, and it is also important for the pilot controlling an aircraft in light conditions close to the ground, particularly in landing. Therefore, poor visibility yields a great restriction for aircraft operations .The natural view of the pilot depends on various meteorological conditions like darkness, dust, fog, rain etc. The degradation in view caused by these conditions can be compensated for partially or even completely by technical means providing artificial vision cues. Such technical means may be based on radar or optical sensor information [1,2].

When dense fog develops along roadways, the safety of motorist is imperiled. Thus, automated visibility monitoring of fog, snow, dust and smoke is of utmost importance. Fog is a large density of small water droplets small enough to "float" in the air. The size of fog particles is typically 5 to 50 μm the reason why fog particles float in the air is the following: The Smaller water drop is the lower is the fall velocity, and for small enough size the time it takes for the droplet to fall to the ground is much longer than its lifetime. In a real atmosphere the air is also constantly moving also vertically which compensates for the motion by gravity for some of the droplets [3, 4, 5, and 6].

2. Visibility

The most understandable measure on visibility is the Meteorological Optical Range (MOR): The simple definition of MOR is how far the objects can be seen. But exactly how far away an object can be seen during foggy conditions in daylight depends on the optical properties of the object such as color, structure a light source or not, and the intensity of the light source. At night time talk about visibility distance to a light source [4].

3. Scattering of light

A light beam is hit a small particle in the air. The light source can for instance be a laser or a LED. The wavelength may be inside or a little outside the visible range. The particle is typically a small water drop constituting fog.

A fraction of the laser light propagating from left to right will be scattered in all directions but with different efficiency by the particle. The light that has changed its propagation direction less than 90 degrees is called forward scattered light, and the light that has changed its direction more than 90 degrees is called back scattered light. All the scattered light is lost for contributing to an image on the retina in the eye. This is the reason why the perception when looking at objects with eyes (or with a camera) during fog is changed. Fig. (1) Shows the back scatter and forward scatter techniques [4, 7].

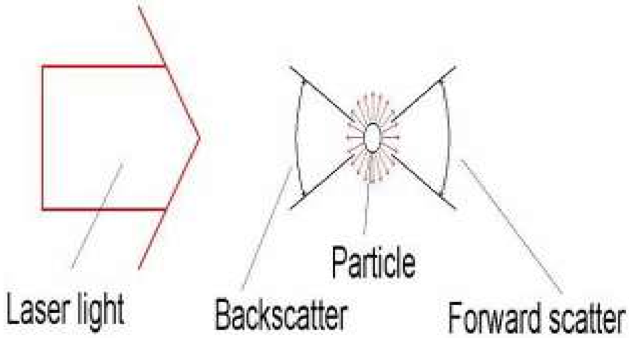

Fig.(1):Back scatter and forward scatter method.

4. Sensing Techniques for Measuring Visibility

A-Transmission Method

One classical method to measure visibility is to measure how much light that is transmitted from a light source to a receiver located at distance- equal 50 m. Fig.(2) shows the Transmission method.

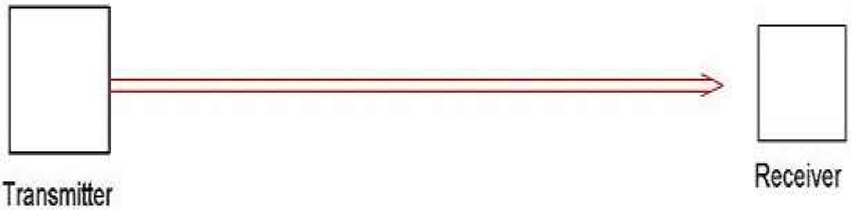

Fig. (2): Transmission method

In foggy weather less light (compared to during clear weather) will reach the receiver because of the scattering along the ray path. The scattered light will of course not be collected by the receiver .The reduction is used as raw data for strait forward calculation of the visibility. The method is for instance used on airports. The visibility along runways, a very important safety parameter on airports, is often controlled this way [1, 4].

B-Forward Scatter Method

The Forward scatter sensors collect light scattered in a forward direction. A typical sensor projects light outward that collides with particles in the air (fog, snow, dust, etc.). These particles scatter light in all directions (primarily forward) and this sensor utilizes the stronger energy scattered forwards toward a receiver that collects the light [1, 7]. Fig. (3) Shows the forward scatter method.

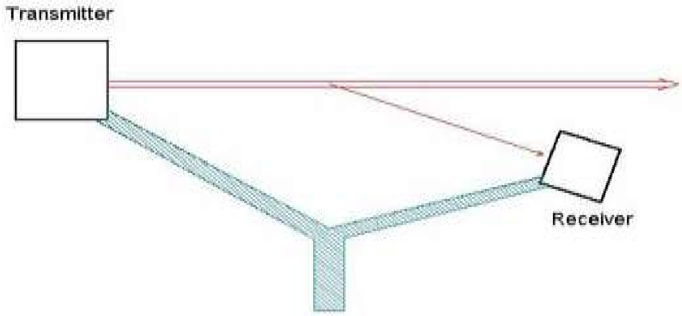

Fig. (3): Forward scatter method

C-Back Scatter Method

As the name implies, backscatter sensors collect light scattered in a reverse or backward direction. the backscatter sensor relies on the weaker energy scattered backwards toward a receiver that collects the light. The technique was popular in the early 1970s before the development of forward scatter sensors. The advantage of the backscatter technique is a small, compact sensor but this is outweighed by the fact that they severely underestimate visibility in snow and are prone to false scattering due to bright light and clogging from blowing snow. Fig.(4) shows the back scatter method.

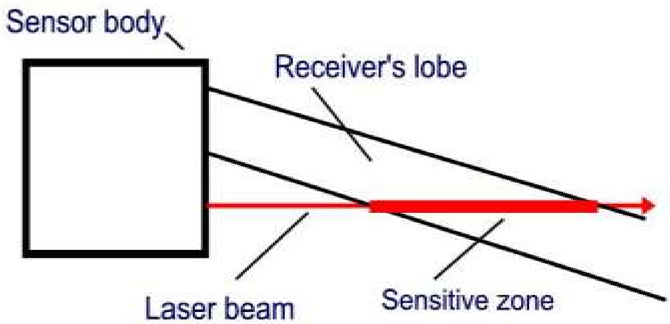

Fig. (4): Back scatter method

The main disadvantage of the backscatter concept is that the optical power reaching the receiver is lower than that in the forward scatter case. This causes lower signal to noise ratio when using the backscatter method but can be compensated for by using high performance electro optic solutions (low noise optical receivers) making range of 10 km possible [1, 4].

5. Theortical Background

The principles of fog detection and visibility measurements are based on light propagation properties in the atmosphere, where absorption and scattering influence the transmitted beam according to the Lambert–Beer law the power loss in the absorbing and scattering environment is proportional to the input power of the beam P_i and the path length of the transmission dR. It leads to the well know formula for the output power p_o of the beam:

$$P_o = P_i e^{-SR} \quad \dots \quad (1)$$

Where S is the extinction coefficient which stands for absorption and scattering The visibility measurements are based on for eq. (1) [1, 8].

So called standard visibility V_n is understood as a daylight visual range of a large dark object seen against the horizon sky as a background ,computed on the assumption that the contrast threshold of the observers eye has a value of K=0.02.

According to Koschmider (1925) the contrast K changes in the same manner as eq. (1) [1, 4].

In practice however, the threshold contrast is estimated sometimes as K=0.05.So, for (p_o/p_i =0.05) obtains [1]:

$$R = V_n = \frac{3}{S} \text{and} \frac{P_o}{P_i} = e^{-3R/V_n} \quad \ldots \quad (2)$$

Equation (2) gives two possible methods of the standard visibility (V_n) measurements:

6 .Transmission Method

According to this method the light attenuation along a known distance (R) is measured, where the standard visibility is

$$V_n = \frac{3R}{\ln \frac{P_i}{P_o}} \quad \ldots \quad (3)$$

From eq. (3) it follows that for a given accuracy of attenuation measurement the shorter is the standard distance R, the lower accuracy of V_n is obtained. Short distance R demand high accuracy of low attenuation measurements. For sufficiently long distances R transmission meters are the most accurate instruments for visibility measurements [1].

- Forward and back scattering methods

In the methods the loss of the transmitted power ΔP is measured, which for short standard ranges R << V_n leads to[1]:

$$\Delta P = P_i - P_o = \frac{P_i 3R}{V_n} \quad \ldots \quad (4)$$

So, the denser the fog, the lower visibility and the more light is scattered and measured by the receiver.

However, it is difficult to measure the whole power loss ΔP, since the light is scattered in all directions and partially absorbed in the given volume of space.

Thus, optical measuring receivers with limited field of view can measure the scattered light in a rather narrow range of angles only. Therefore, instead of measuring the total scattered power ΔP from a given volume of space d which is illuminated by the power density E, only a part of it Δp_m is measured .The measured power Δp_m can be calculated by integrating the scattered light intensity I(θ):

$$\Delta P_m = 2\pi \int_0^u I(\theta) \sin(\theta) d(\theta) \ldots \quad (5)$$

Where (u) is the half of receivers field of view. Light Intensity I(θ) is produced by many elementary space volumes (dv) which are illuminated by the power density E. Each of them scatters light according to the scattering function β (θ) [1]:

$$I(\theta) = E\beta(\theta)dv \quad \ldots \quad (6)$$

According to eq. (5) the scattered power can be calculated, if the scattering function β(θ) and the scattering volume v are known .The latter is the volume of intersection of the transmitting beam and the receivers field of view.

In practical instruments two possible solutions are employed. One possible approach is to measure back scattered light in the direction θ opposite to the illuminating light θ ≈180°.

According to second solution the forward scattering in the directions close to θ ≈0 is measured. The light scattered in forward direction is nearly two orders higher, than the backscattered [1].

7. Experimental work

The system to measure the visibility requires a fog generator and optical system to detect and measure the fog:

a- Fog Generator

The fog generator is made of water container, ultrasonic transducer (piezoelectric) and air fan. Fig. (5a) and (5b) shows the Fog generator.

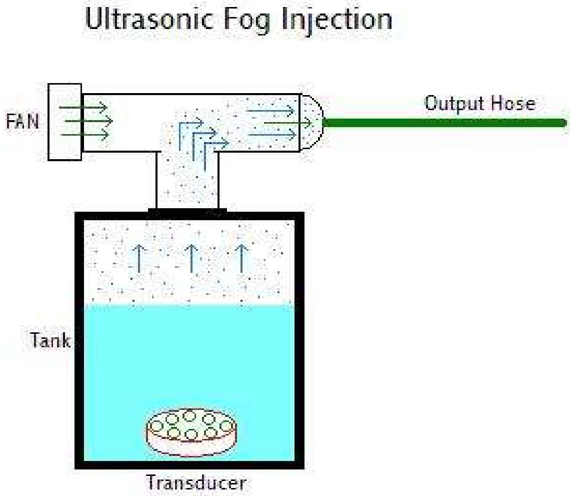

Fig.(5a):Fog generator technique

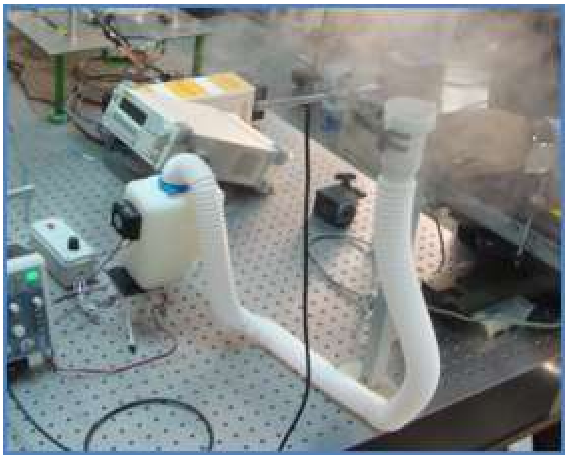

Fig. (5b): Test fog generator

b- Forward Scattering Visibility Fog Sensor

The block diagram of the forward scattering visibility fog sensor is shown in Fig.(6). The main block of the system consists of two head, optical transmitter and optical receiver, where the visibility is to be measured. Optoelectronic transmitter includes IR LED diode at wavelength 850nm connected with driver modulated circuit by the square made of 300Hz frequency. Optoelectronic receiver includes silicon p-i-n photodiodes for scattering signal detection were chosen because of their good stability and responsively for the LED radiation. The receiver contains a low noise amplifier circuit and IR optical filter. The experimental work of forward scattering is shown in fig. (7).

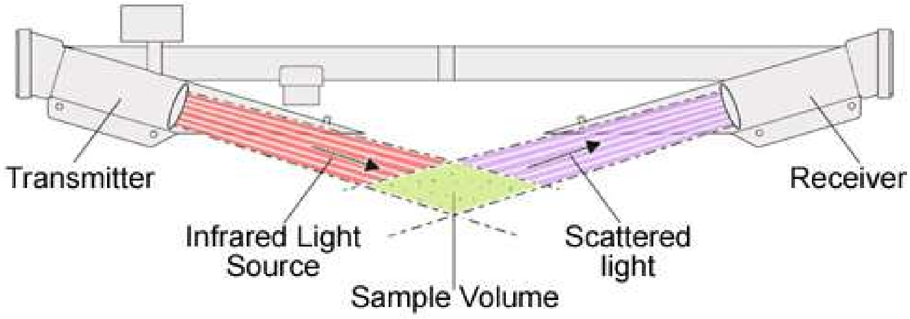

Fig.(6): Block diagram of the forward scattering visibility fog sensor

Fig.(7):Test forward scattering fog sensor

8. Results and discussion

a-Test of the Fog Generator

The illustrated setup of the fog generator is shown in fig. (5b), when system is power on the resonating frequency obtained between (1.6 - 2) MHz, this produces high-energy vibrations which cause the water to turn into fog. The transducer creates oscillation of high frequency on the water surface. This causes the water to turn into vapor. High pressure compression waves are created on the water surface, causing vapor molecules to be released into air. Water particles in the fog are of a size less than 5 microns. Ultrasonic foggers cannot be run dry; they need sufficient amount of water to function .The water deionized or distilled is used. Unlike thermal or heat-based fogger, the fog generated by an ultrasonic fogger is cold and wet.

b- Test of the Forward Scattering

The sensor is sensitive for fog particles in a zone about 15 cm between two heads. These particles are normally the microscopic water particles constituting fog, but the most indications of low visibility due to fog. Optical energy scattered by interaction with particles in the sample volume is measured at a scatter angle of 42^o. This angle is selected because it provides linear scattered signal amplitude for the particle size distribution of interest (haze, fog, rain, and snow), as well as the best response in all weather condition. This information is confirmed by the organizations by National Weather Service NWS), Federal Aviation Administration (FAA), and World Meteorological Organization (WMO) all recognize forward scatter the as preferred technique. Fig.(8) represents variations of fog density with output scattering voltage.

Figure (8) shows that without fog density has a output scattering voltage is (1.2V) , while the increasing the concentration of the fog density leads to increase the value of scattering voltage , the liner relationship is shown in fig. (8).

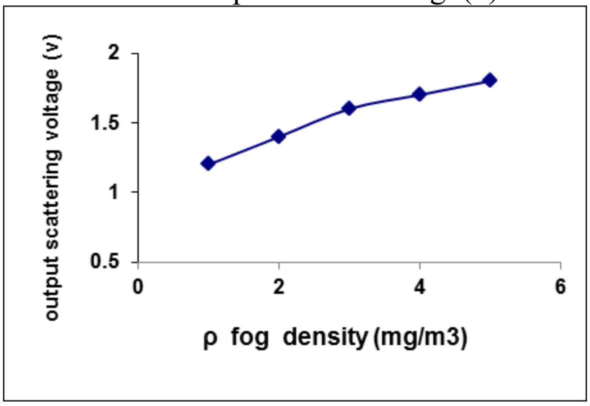

Fig.(8): variations of fog density with output scattering voltage

The MOR is calculated by the converting the received signal strength (extinction coefficient, S) by using Koschmeider's formula, where visibility=MOR (Km) = 3/S, when the fog generator system is off state there is no scattering effects (clear weather).At good visibility the extinction coefficient is near to zero and it increases as the visibility decreases. The extinction coefficient can also be named fog density. When the scattered power exceeds the adequate level. The DC signal is proportional to the scattered power . The analog signal converted and read by the microprocessor. The microprocessor analog controls is calibrated to gives the visibility directly (VIS =1 km gives 1 Volt, and VIS = 500 meters gives 0.5 Volt etc, up to 4000 meters). This examination and calibration the system within the laboratory so it requires testing and calibration of the system in foggy conditions outside the laboratory and writes the software works with this system.

9. Conclusion

This study has presented optical forward scattering techniques for measuring atmospheric visibility that rely on the principle of light scattering by particles in the air. In this paper we will examine the forward scattering technique and their advantages. This scattering technique is cheaper; a smaller and maximum operating visibility is 7Km and more accurate readings in all weather conditions, while back scatter techniques operating maximum ranges of 4 km .These systems are safe to the eye because of the LED used. Forward scattering angle used about 42^{o} in the forward direction provides the best response in all weather conditions.

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