Design and Development of an Optical Sensor System to Measure Visibility of Air

S. Nurulain, R. M. Ramli, H. Manap, and Mohd Anwar Zawawi

Abstract Visibility is a measure of the distance at which an object or light can be clearly recognized. Visibility for a medium depends on the visible light transmission (VLT). This paper describes the development of VLT measurement system to measure the visibility of air. In recent years, there are many types of devices that can measure VLT. But the existing method and technique have their own disadvantages such as gigantic set up, costly, only can be used in small area and fail to function at night. Therefore, this research will focus on how to measure the visibility by using an open path optical method. The experimental setup for VLT measurement in this research consists of a laser pointer as a light source and spectrometer as a detector. The amount of light that passes through a few series of known-VLT thin films is measured and the percentage values of the measured thin film are set as a measurement base. This new proposed technique is believed to cater the problem mentioned above as the experimental setup is simple, small in size and can measure visibility in any light condition.

Keywords Visibility · Optical · Visible light transmission

1 Introduction

Visibility information is essential in dust and air quality monitoring which often require frequent and accurate real-time observations of visibility [1]. In the transmission process of light, an electromagnetic radiation gets impaired due to emission and absorption of different radiation wavelengths by the medium of propagation. Interaction of light packets i.e. photons with fundamental particles like electrons, atoms, ions and impurities such as fog, dust, smoke, maritime spindrift particles

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called aerosols etc. affects visibility. Visibility at certain medium depends on the visible light transmission (VLT). VLT is simply the measurable amount of solar visible light (daylight) that travels through a medium. A medium with a high VLT allows most of the daylight to pass through while a lower VLT restricts the majority of light from entering a medium. In a modern world, there are many devices that are used to measure VLT. Some of the devices like 3 M transmission meter is only suitable to be used to measure VLT for thin films [2]. There are also many visible light meters (VLM) distributed by a company called EDTM, Inc. However this transmission meter can measure the VLT of thin object such as glass. These devices are not suitable to be used to measure VLT of air in open space environment or at a wide area. The air VLT measurement system for a wide area and open space are already exist such as using a Laser Absorption Spectrometry (LAS) technique. However it has a gigantic set up and it is very costly [3].

There is also a device called Lux meter and it is used to measure intensity or brightness of an area [4]. However Lux meter can only be used in a small area or point measurement. It is not suitable to be used in an open wide area such to measure visibility at the airport. The other VLT measurement system such as a photography technique fails to function well at night and cannot perform real time measurement [2]. This is because of the low light condition and it faces a several errors especially in rainy, foggy and smoky conditions. Haze is one of the major factor that can interrupt the visibility. This haze phenomenon not only faced in Malaysia but also in entire world. People need to know how far they can see during haze. Therefore a new setup using a laser pointer as a light source to develop the air VLT measurement system is proposed. This new proposed technique is believed to cater the problem mentioned above as the experimental setup is simple and small in size. Besides, it can function well in a low light condition and can be used at an open wide environment. As a result, people can easily measure how far they can see.

2 Methodology

2.1 Sensor System Design

This open path optical method use laser pointer as a light source and spectrometer as a detector. At the beginning, a VLT of thin film will be measured and the percentage of this VLT thin film will be used as a measurement base in order to measure the visibility of air. Smoke will be use to increase the intensity of air. Increasing in smoke reading will be justify by using a commercialize sensor called Dustmate. A 100 cm chamber is used in order to test light source stability and to measure the VLT of the smoke. Both end part of the pipe are closed using an end caps as shown in Fig. 1. These end caps can be easily removed from the pipe. The inner side of the chamber is sprayed with black paint. This is to reduce the reflection of the light inside the chamber.

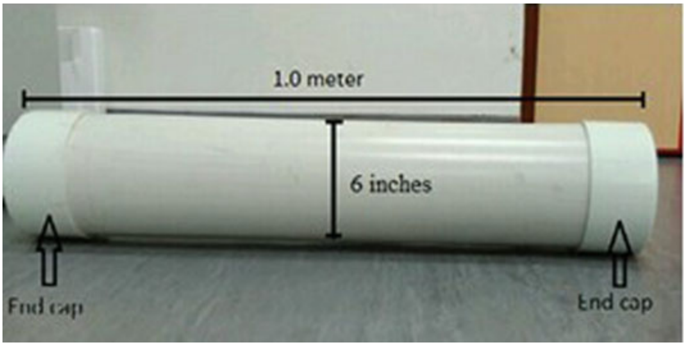

Fig. 1 Chamber

2.2 *Laser Pointer*

Visible light mostly comes from artificial sources such as fluorescent or tungsten devices, light-emitting diode, laser and many more [5]. This light source can be separated into two different types. The first type transmits a continuous wave as reported by Kudlinski et al. [6] and this wave requires an external modulator at its optical output. Second type of the light source transmits modulated light. According to Yuan et al. [7], a modulated type does not need any external modulator. LASER is stand for Light Amplification by Stimulated Emission of Radiation. Each laser emit light at different wavelength depends upon the material from which the laser crystal, diode, or gas composed and also the color emitted by the laser itself [5].

A battery operated laser pointer is used as a light source in this research. It can emit green color beam laser emission at range between 532–538 nm and can transmit up to 8000 m as claimed by manufacturer. Green color is chosen among all the color in visible light region because this green color is fifty times brighter than red laser. Besides, it is also have long-term reliability and stability due to the low power density and thermal effect [8]. A high and low temperature does not affect the performance of green laser itself. This laser pointer is made up from aerometal material with the dimension 150 mm × 28 mm.

2.3 *Thin Film*

A few series of known-VLT thin films are used in this research. At the initial stage, these thin films are measured by using a commercial transmission meter (3 M Transmission meter) in order to validate the percentage of VLT of each thin film. Then, the values of VLT thin film are measured using open path optical method in percentage value.

2.4 Detector (Spectrometer)

Spectrometer is a device that used to split light into a spectrum. It can analyse the detected substance or light in a short time and it is very easy to use. Besides, spectrometer also is used in astronomy to analyse the chemical composition of stars and planet. The disadvantage of this detector is its price and the repair cost is expensive relatively. Electronic components in this device may also generate noise that decreases the measurement accuracy and the sensitivity of device [9]. Spectrometer are use as a detector in this research.

2.5 Dustmate

A Dustmate is needed in order to validate the amount of smoke changes in the smoke chamber. DustMate from Turkey Instruments Ltd is chosen as a second measurement device in this research. Practically, the DustMate had been designed to detect sources of workplace airborne dust and fumes even at very low concentrations. It is a handheld instrument with a very fast response where it can measure Total Suspended Particle (TSP), PM10, PM2.5 and PM1 simultaneously in real time.

3 Experimental Setup

Two sets of experimental setup was arranged in order to measure the VLT and the visibility of air by using an open-path optical method. First experimental setup consists of light source, glass plate holder, laminated thin film, spectrometer and PC installed with Spectrasuite software in order to measure VLT of thin film as shown in Fig. 2. Counts of intensity from each thin film are obtained and recorded in percentage. These data are used as a reference.

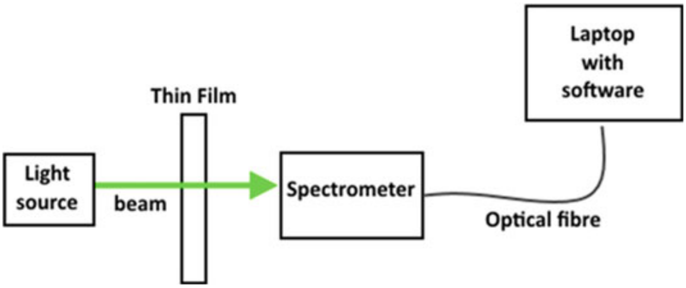

Fig. 2 Block diagram of experimental setup to measure VLT of thin film

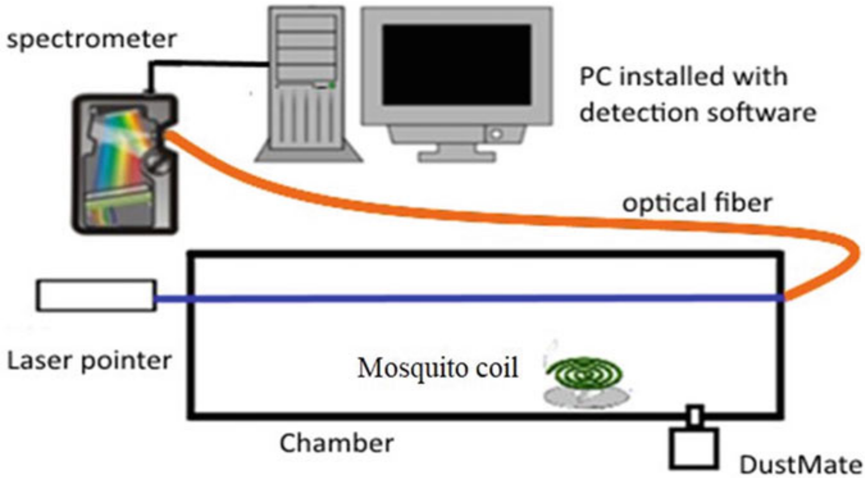

Fig. 3 Experimental setup to measure visibility of air consist smoke in chamber

Air visibility varies when a smoke is generated in a chamber using a mosquito coil. The absorption of light that passes through the air is measured and the intensity counts in the selected region was calculated and analyzed. The comparison between the references data from known-VLT thin film result and the measured data from air that consist of smoke was analyzed to measure the visibility. Dustmate is place inside the chamber to justify the increasing value of the smoke. Figure 3 shows the experimental setup to measure visibility of air consist smoke in chamber.

3.1 Beer Lambert Law

In this research study, we proposed an optical-path technique to measure the visibility of air. Visible light transmission (VLT) will affect the visibility. As the percentage of VLT increase, light intensity will also increase. The method used in this project is based on an open-path optical technique. The path length of the travelled light will influence the interaction between amount of the tested sample and the light. A principle of visibility measurement mostly depends on light propagation properties where the light is absorbed and scattered.

In optical method measurement, the Beer-Lambert law is used to relate the absorption of light to the properties of the material where light is travelling. The Transmittance, T of the travelling light can be calculated from the ratio of the transmitted Intensity, I and incident Intensity, I0 as shown in Eq. 1. Absorbance, A as shown in Eq. 3.2 has no unit. Using Eq. 2, the absorption of light that passed through the air can be determined if the incident and the transmitted intensity are known. Light intensity that travelling through a medium will be exponentially reduced with respect

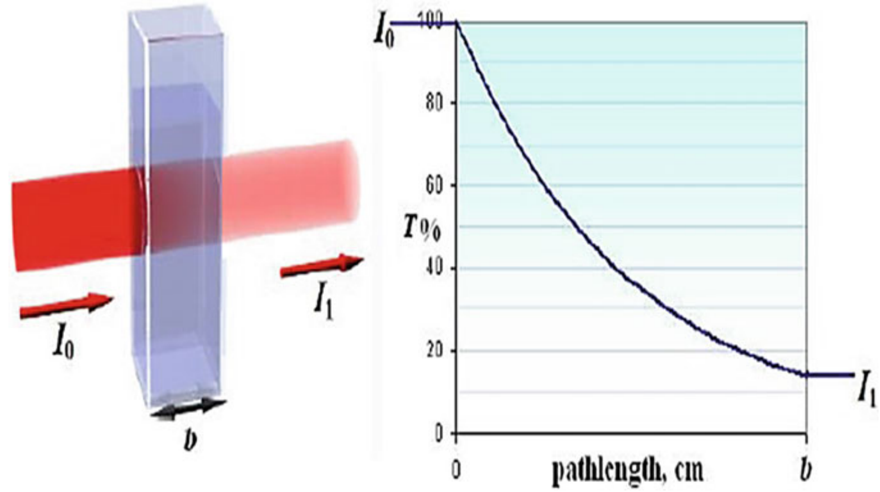

Fig. 4 Light absorption intensity over path-length

to the path-length, b as shown in Fig. 4 [10].

$$T = I/I_0 \tag{1}$$

$$A = -\ln(T) \tag{2}$$

4 Results and Discussion

VLT of thin-film is measured by using open path optical method. The wavelenghth is taken at 537.65 nm because the peek at that wavelenghth is much appriopriate to be used in labolatory test. It is expected that the thin film with higher percentage of VLT will have a higher intensity of spectrometer reading. Based on Fig. 5, it is clearly shown that the higher the VLT percentage of thin film, the higher intensity of light detected by the spectrometer. The percentage of VLT-thin film labelled by manufacturer was 10, 35, 50 and 60%. But the result of thin film verification by the commercial transmission meter is are slightly lower than the percentage value labelled by the manufacturer. This is might due to the thin films are laminated on the glass plate that has different ability to absorb some of the light transmission. These measured values are acceptable as it is aligned with the transmission meter specification whereby it has ±2% accuracy. The percentage of VLT-thin film recorded by this transmission meter was 10%, 35%, 48% and 69% respectively.

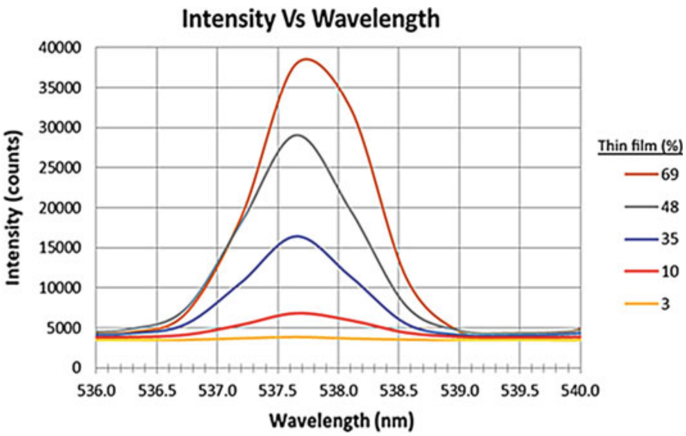

Fig. 5 Intensities of thin films at selected peak for VLT measurement

The development of this VLT measurement system is based on the data obtained in the first experiment. According to the Beer Lambert Law explained before, the transmittance, T of the travelling light can be calculated from the ratio of the transmitted, I and incident intensity, I0 as shown in Eq. 1. To develop the VLT measurement system, a relationship between the transmittance, T and VLT percentage must be obtained. Therefore a graph of transmittance, T versus VLT percentage at selected wavelength (537.65 nm) is plotted using Microsoft Excel software as shown in Fig. 6.

In an open environment, smoke is a major factor that can affect visibility. Therefore, an experiment for VLT measurement due to present of smoke is carried out. The setup for this experiment is shown in Fig. 3. A mosquito coil is chosen because it produces smoke constantly over time when burning. It can be assumed that the smoke accumulates consistently in the chamber and the visibility will drop. The result of the VLT measurement using optical system is shown in Fig. 7. The result shows the VLT drop over time and this is aligned with the assumption that VLT will drop when more smoke accumulates in the chamber.

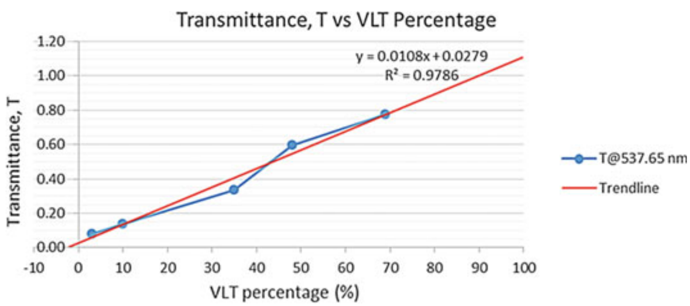

Fig. 6 Transmittance, T versus VLT percentage of thin films

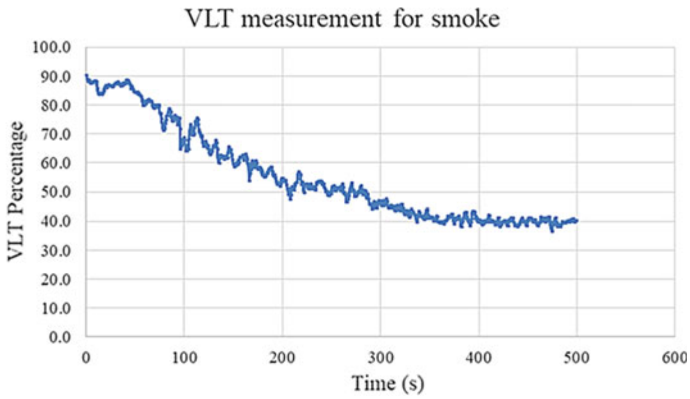

Fig. 7 VLT measurement for smoke at 537.65 nm

A commercial device called DustMate is used in this experiment to justify the VLT measurement. It is a device to measure the concentration of particle in air. The smoke particle concentration in the gas chamber is measured so that it can be relate with the opacity or VLT percentage. The DustMate sensor tip is placed in a chamber to measure the quantity of smoke. The reading of the DustMate is taken for every 20 s and the result is shown in Fig. 8.

As can be seen from Fig. 8, the amount of Total Suspended Particle in the chamber is increased over time. Thus it can be said that the smoke in the chamber is accumulated. Therefore the visibility in the chamber is reduced and the VLT percentage will drop as well. This is aligned with the result of VLT measurement done by optical sensor system as shown in Fig. 7.

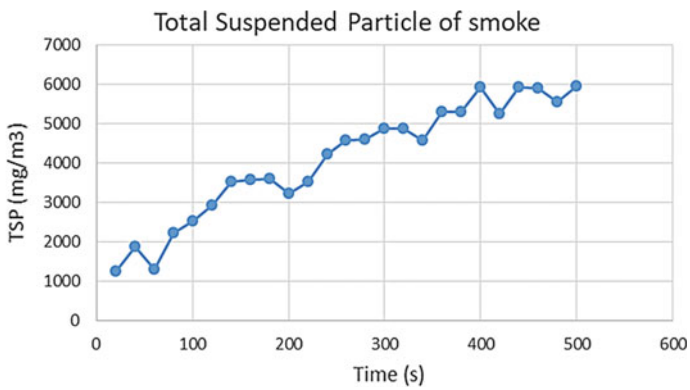

Fig. 8 Total suspended particle reading by DustMate

5 Conclusion

The open path optical VLT measurement system has shown its ability to measure VLT of air in a chamber that consist of smokes. Smoke is the major contributor to visibility measurement in an open area. It is found that the VLT measurement system is able to detect an accumulation of smoke in a chamber. However it can measure the VLT of air for a short duration only. This is due to the intensity of light source used in this experiment is not stable. Therefore a replacement of the light source could reduce the inaccuracy of this sensor reading. However the cost of replacement of a more stable light source should be compromised. For future work, many possible things can be carried out to achieve better performance and reduce the cost of the VLT measurement system. For instance, the spectrometer can be replaced by a visible range sensitive ceramic photodiodes.

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